MONTHLY NOTICES

OF THE

ROYAL ASTRONOMICAL SOCIETY

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MEETING OF 1942 SEPTEMBER 11

Professor S. Chapman, President, in the Chair

The election by the Council of the following Fellow was duly confirmed:—

Edwin George Essery, M.R.C.S., L.R.C.P., St. Audry's Hospital, Melton, nr. Ipswich, Suffolk.

The following candidates were proposed for election as Fellows of the Society, the names of the proposers from personal knowledge being appended:—

Charles Going Ambrose, M.D., c/o Lloyds Bank, 27 Whitechapel High Street, London, E.C. 1 (proposed by Sydney Chapman);

Edward James Cope, Mendip, West Malvern, Worcs. (proposed by I. F. H. C. Carr-Gregg);

Robert James Porter, B.Sc., 22 Marlborough Avenue, Hessle, East Yorkshire (proposed by L. J. Comrie); and

P. A. Scott-Iversen, 11A Newbold Terrace, Leamington Spa, Warwickshire (proposed by Herbert Dingle).

Sixty-one presents were announced as having been received since the last ordinary meeting, including:—

Frank Debenham, Astrographics (presented by the author);

MS. letters written by and copies of various printed articles which belonged to Messrs. Edward and Nathaniel Pigott and John Goodricke (presented by Major George Anne);

Washington, National Geographic Society, Contributed Technical Papers. Solar Eclipse Series, No. 2. National Bureau of Standards Solar Eclipse Expedition of 1940 to Brazil (presented by the National Geographic Society).

CORRECTION

Fellows will be very glad to learn that the report of the death of Dr. C. D. Perrine, communicated to the Society on 1942 May 8 (*M.N.*, **102**, 133), was erroneous. The Officers deeply regret the publicity thus given to the report.

ON THE NATURE OF RED GIANT STARS

F. Hoyle and R. A. Lyttleton

(Received 1942 June 4)

1. In a previous paper* the normal equilibrium configuration of a star has been shown to consist of a convective core surrounded by an envelope in radiative equilibrium. For uniform composition with ratio of specific heats 5/3 and neglecting radiation pressure, the equilibrium equations are

$$\left.\begin{aligned} &\frac{d}{dr}\left\{\frac{\mathfrak{R}}{\mu}\cdot\bar{\rho}\bar{T}\right\} = -G\bar{\rho}\bar{M}(r)/r^2, \qquad \frac{d}{dr}\bar{M}(r) = 4\pi r^2\bar{\rho}, \\ &\text{together with} \qquad \bar{\rho}/\bar{\rho}_0 = (\bar{T}/\bar{T}_0)^{3/2} \qquad \text{in the convective core,} \\ &\text{and} \qquad \frac{d}{dr}\{\tfrac{1}{3}ac\bar{T}^4\} = -\bar{\alpha}(1-X^2)\bar{\rho}^2\bar{T}^{-3\cdot5}L(r)/4\pi r^2 \quad \text{in the radiative envelope.} \end{aligned}\right\} \qquad (1)$$

Here $\bar{\rho}$, $\bar{T}$ and $\bar{M}(r)$ denote the density, temperature and interior mass at distance r from the centre all expressed in c.g.s. units, X is the mass of hydrogen per gram, while $\bar{\alpha}$ is a coefficient of opacity. In the radiative envelope $L(r) = L$, the luminosity of the star, to a high degree of accuracy.

For numerical integration of (1) it is more convenient to express the density and temperature as fractions of the central values $\bar{\rho}_0$, $\bar{T}_0$ and the mass $\bar{M}(r)$ as a fraction of the quantity

$$4\pi\bar{\rho}_0\{5\mathfrak{R}\bar{T}_0/8\pi\mu G\bar{\rho}_0\}^{3/2},$$

and when so expressed the ordinary symbols ρ, T and M are used. Also r is replaced by a dimensionless variable z defined by

$$r = \{5\mathfrak{R}\bar{T}_0/8\pi\mu G\bar{\rho}_0\}^{1/2}z.$$

Writing $1/z = y$, equations (1) then take the form

$$\left.\begin{aligned} &\frac{d}{dy}(\rho T) = 2\cdot5\rho M, \qquad \frac{dM}{dy} = -\rho y^{-4}, \\ &\text{with} \qquad \rho = T^{3/2} \quad \text{in the convective region,} \\ &\text{and} \qquad \frac{dT}{dy} = \kappa(1-X^2)\rho^2T^{-6\cdot5} \quad \text{in the radiative exterior.} \end{aligned}\right\} \qquad (2)$$

The factor κ is proportional to $L(z)$ and at the beginning of the radiative region must make the value of the temperature gradient continuous with that at the limit of the convective core. The actual extent of the two portions is then determined by the requirement that ρ and T must vanish together. The problem of finding the configuration satisfying this condition has been considered by Cowling † for the case when κ is constant.

The requisite integrations have been repeated by the authors and only small changes from the Cowling solution have appeared. The behaviour of a solution of (2) can be conveniently followed by means of the variation of the effective polytropic index n which is defined by the relation

$$n+1 = \frac{d\log p}{d\log T} = \frac{2\cdot5M}{\kappa(1-X^2)}\cdot\frac{T^{6\cdot5}}{\rho^2}. \qquad (3)$$

* *M.N.*, 102, 177, 1942. † *M.N.*, 96, 42, 1935.

Since $d \log p/d \log T = d \log \bar{p}/d \log \bar{T}$, we have in the radiative region

$$n+1 = \frac{16\pi}{3} \cdot \frac{acG\mu\bar{M}\bar{T}^{6\cdot5}}{\Re\bar{a}L(1-X^2)\bar{p}^2}. \tag{4}$$

For the solution of (2) sought, ρ and T tend to zero simultaneously and the value of n must tend to 3·25 from below as the surface of the star is approached. The radius of the convective core $z = \zeta$ for which this condition is satisfied is found by trial integrations with various starting values for ζ. The calculations were made by means of Taylor's series and it was found that the appropriate value of ζ is very close to 1·19238, the corresponding value of κ being 0·19742. The values obtained for T, ρ and M at intervals of ·05 in y are given in the accompanying table:

y	T	ρ	M
0·80	0·7680	0·6722	0·5165
·75	·7418	·6343	0·6074
·70	·7125	·5894	0·7184
·65	·6795	·5368	0·8545
·60	·6422	·4759	1·0210
·55	·5997	·4067	1·2236
·50	·5511	·3305	1·4668
·45	·4957	·2503	1·7521
·40	·4324	·1712	2·0736
·35	·3610	·1009	2·4124
·30	·2814	·0471	2·7314
·25	·1950	·0148	2·9775
·20	·1045	$1·97 \times 10^{-3}$	3·1041
·15	·0119	$1·69 \times 10^{-6}$	3·12634
0·14354	0·00	0·00	3·12635

The radius of the star is therefore given by $z_s = 6·967$, a value about 0·8 per cent. less than that given by Cowling, who however obtained the value $\zeta = 1·188$ for the limit of the convective core. The distribution given by the above table will be referred to as the standard configuration.

2. As the surface of the star is approached dT/dy and $\rho/T^{3·25}$ tend to constant limiting values. To obtain an indication of the accuracy of the later treatment in this paper we consider the effect of fitting on to the standard configuration at radial distance $y = y_0$ an atmosphere in which $\rho/T^{3·25}$ and therefore dT/dy are constant and equal to their values at $y = y_0$. The changes in radius $z_s = 1/y_s$ and mass for a number of values of y_0 are shown in the following table:

y_0	y_s	Percentage Error in y_s	Atmosphere Mass (less than)	True Mass	Percentage Error in Total Mass
·18	·14325	0·2	·0057	·0053	0·0
·20	·14299	0·4	·0246	·0223	0·1
·25	·14024	2·3	·1629	·1489	0·5
·30	·13106	9·2	·4571	·3950	2·1

From this it is clear that only trifling changes from the earlier solution are introduced by fitting on such an atmosphere at $y_0 \leqslant 0·25$ and that even if $y_0 = 0·30$ the changes are not large. Accordingly we can get a satisfactory approximation to conditions in the outer part of a star by assuming that $\rho/T^{3·25}$ is constant.

3. We next consider the effect on the standard configuration of a change in molecular weight in the outer part of the star. To simplify the analysis the change is regarded as taking place discontinuously, the value being μ from the centre to $y = y_0$ say, and μ' outside $y = y_0$. A continuous change in a layer of small depth could equally be discussed, but it can be verified that this case leads to no essential difference from that of a sudden change. We investigate what values μ'/μ may take without rendering the star unstable.

The conditions to be satisfied at $y = y_0$ are more conveniently dealt with by measuring the density and temperature in c.g.s. units. We denote their values for $y > y_0$ by $\bar{\rho}$, $\bar{T}$ and for $y < y_0$ by $\bar{\rho}'$, $\bar{T}'$. Then $\bar{\rho}$, $\bar{T}$ satisfy (1), whereas $\bar{\rho}'$, $\bar{T}'$ satisfy equations given by replacing μ, X in (1) by μ' and X'. At the interface the pressure and temperature must be continuous so that

$$\bar{\rho}/\mu = \bar{\rho}'/\mu' \quad \text{and} \quad \bar{T} = \bar{T}'. \tag{5}$$

It is supposed that the interface occurs sufficiently far from the centre to permit the use for $y < y_0$ of the approximation

$$\bar{\rho}'/\bar{T}'^{3\cdot25} = \text{constant}, \tag{6}$$

which requires that only a small fraction of the mass shall lie outside the interface. Then by means of (4) applied at both sides of $y = y_0$ and using (5) we obtain the single condition

$$\frac{\mu(1-X^2)}{\mu'(1-X'^2)} = \frac{4\cdot25}{n(y_0)+1} \tag{7}$$

where $n(y_0)$ is the value of the effective index at the inner side of the interface, that is for the $\bar{\rho}$, $\bar{T}$ solution. For given μ, μ' and y_0 (7) specifies the value of $n(y_0)$ and this is sufficient to determine uniquely the solution $\bar{\rho}$, $\bar{T}$ or the equivalent solution ρ, T. In general such a solution will involve a central convective core of radius different from that for the standard configuration.

The least value that the index $n(y_0)$ can take consistent with the mechanical stability of the star is 1·5, so that the largest possible value of the right-hand side of (7) is 17/10. By taking this value together with a central value of μ or X, relation (7) enables us to determine the limit of permissible values of μ' or X' in order that radiative equilibrium may be possible in the atmosphere. Taking $\mu = 2/(1+3X)$, the following solutions of (7) are readily obtained:

$\mu = 2\cdot0$	$X = 0\cdot00$	requires	$\mu' = 1\cdot22$	$X' = 0\cdot21$	$\mu'/\mu = 0\cdot61$
$\mu = 1\cdot6$	$X = \cdot08$	,,	$\mu' = 1\cdot03$	$X' = \cdot31$	$\mu'/\mu = \cdot65$
$\mu = 1\cdot2$	$X = \cdot22$	,,	$\mu' = 0\cdot85$	$X' = \cdot45$	$\mu'/\mu = \cdot71$
$\mu = 0\cdot8$	$X = \cdot50$	,,	$\mu' = 0\cdot66$	$X' = \cdot68$	$\mu'/\mu = \cdot82$

Thus the greatest difference in the values of μ and μ' occurs for $X = 0$ and it can easily be seen that it also occurs for the limiting value 17/10.

The important result brought out by this analysis is that if a value of μ'/μ less than 0·61 were to occur, an atmosphere *in radiative equilibrium* could not be fitted on at all. For at the limit of the μ region the value of n must be at least 1·5, while across the interface it would increase immediately to above 3·25 and then continue to increase with z. This would mean that ρ and T could not tend to zero simultaneously, so that the configuration would not correspond to a physically permissible equilibrium state. The possibility of convective equilibrium of such an atmosphere is even more definitely ruled out, since it would require n to be 1·5 in the atmosphere and this is already the least value n can have in the μ region. Accordingly it appears that if such a large discontinuity of composition occurred in a star no configuration of equilibrium would exist for the atmospheric portion and therefore that it must take up some dynamic state until a redistribution of the material occurs that permits an equilibrium state to be resumed. This conclusion it will be observed is not in any way dependent on the numerical approximations adopted elsewhere in this paper.

4. We consider now values of $\mu'/\mu \geqslant 0\cdot61$ so that an atmosphere can be in radiative equilibrium. As already mentioned the star will not be in the standard configuration even in the interior part $y > y_0$. For given μ and μ', with the change occurring at y_0 say, a value must first be found for the radius of the convective core ζ such that at y_0 condition (7) is satisfied. The direct solution of this problem would involve very arduous arith-

metic, but since no special significance attaches to any particular value of y_0 or μ'/μ (so long as it is $\geqslant 0{\cdot}61$) we can adopt a reverse argument. That is we can begin with a value of ζ slightly greater than that of the standard configuration and integrate out to some value y_0 of y at which n remains just above 1·5. With the value then obtained equation (7) determines μ' in terms of μ.

We shall consider a number of numerical examples reached in this way. The temperature function $T(y)$ for such solutions is found to be systematically less than the corresponding function for the standard configuration, while the amount of the difference gets progressively larger as y diminishes. On the other hand the density is systematically larger than in the standard solution as a rule, while the mass function is not importantly changed. Thus $n(y)$ is systematically reduced also by a progressively increasing amount with decreasing y. Since in the outer part of the star, $y < 0{\cdot}3$ say, ρ and T are both much less than unity, only small changes in ρ and T are needed to reduce n to the value 1·5.

5. The main feature that the present discussion seeks to bring out concerns the radius of these composite configurations.

Let $\rho(y)$, $T(y)$ and μ denote the density, temperature and molecular weight for $y > y_0$ and $\rho'(y)$, $T'(y)$ and μ' the values for $y < y_0$. Then on the two sides of $y = y_0$ we have

$$\frac{dT}{dy} = \kappa(1 - X^2)\rho^2 T^{-6{\cdot}5}, \qquad \frac{dT'}{dy} = \kappa(1 - X'^2)\rho'^2 T'^{-6{\cdot}5}.$$

Hence at $y = y_0$ using (5) we have

$$\frac{dT'}{dy} = \frac{1 - X'^2}{1 - X^2} \cdot (\mu'/\mu)^2 \cdot \frac{dT}{dy}. \tag{8}$$

Thus the effect of the change in μ is to alter the temperature gradient by the factor indicated in (8) and clearly when this number is less than unity the radius of the star may be larger than in the standard configuration. By means of (3), the definition of n, equation (8) can be written

$$\frac{dT'}{dy} = \frac{1 - X'^2}{1 - X^2} \cdot \left(\frac{\mu'}{\mu}\right)^2 \cdot \frac{2{\cdot}5M}{n+1} = t' \text{ say.} \tag{9}$$

For the temperature in the atmosphere we then have

$$T' - T'(y_0) = t'(y - y_0). \tag{10}$$

Hence the surface value of y, which we denote $y_s = 1/z_s$ say, is given by

$$y_s = y_0 - T'(y_0)/t'.$$

The mass of the atmosphere can readily be estimated. For we have

$$T' = \frac{y - y_s}{y_0 - y_s} \cdot T(y_0) \quad \text{and} \quad \rho' \propto T'^{3{\cdot}25},$$

so that the mass is given by

$$[M]_A = \int_{z_0}^{z_s} \rho' z^2 dz = \rho'(y_0) \int_{z_0}^{z_s} \left(\frac{y - y_s}{y_0 - y_s}\right) \cdot z^2 dz.$$

This last expression is integrable in finite terms but the resulting function is extremely cumbersome. It is clear however that no serious error is produced by changing the index from 3·25 to 3 and this makes the integration very simple. The value so reached will be an overestimate of the mass. We then have

$$[M]_A < \frac{\mu'}{\mu} \cdot \rho(y_0)(y_0 - y_s)^{-3} \left[\log z - 3y_s z + \tfrac{3}{2} y_s^2 z^2 - \tfrac{1}{3} y_s^3 z^3\right]_{z_0 = 1/y_0}^{z_s} \tag{11}$$

The upper limits to the mass given in the second table above were computed from this formula.

6. The effect of a change in composition in a number of cases is shown in the following table which gives the values of μ', y_s and z_s for various values of ζ, y_0 and μ, the calculations being made as explained.

ζ	y_0	$n(y_0)$	μ	μ'	y_s	z_s
			2·0	1·22	·0565	17·7
1·1924	·274	1·5	1·6	1·03	·0728	13·7
			1·2	0·85	·0909	11·0
1·1924	·28	2·046	2·0	1·457	·1203	8·3
1·19243	·29	1·52	2·0	1·22	·0405	24·7

Since for the standard configuration $z_s = 6{\cdot}967$, the reduction in molecular weight can evidently lead to a great increase in radius. As might be expected the increase is greatest when the change in μ is greatest and when $n(y_0)$ is least. The analysis therefore shows that a change in the composition of the atmosphere of the kind proposed would cause the star to have exceptional radius—the star would become a giant.

These results assume that $\rho' \propto T'^{3\cdot25}$ and this approximation is valid when the mass of the atmosphere is small. It is found by (11) that in the first example for which $z_s = 17{\cdot}7$

$$[M]_A < 0{\cdot}48 \quad \text{and} \quad M(y_0) = 2{\cdot}87,$$

while the example of radius 24·7 corresponds to

$$[M]_A < 0{\cdot}82 \quad \text{and} \quad M(y_0) = 2{\cdot}79.$$

Thus while $[M]_A$ is fairly small it is not negligible and therefore some slight error in the calculated radius would appear likely.

It is possible to choose ζ, y_0 and μ such that these approximate formulæ give $y_s = 0$ or $z_s = \infty$. Actually if $\zeta = 1{\cdot}193$, $y_0 = 0{\cdot}35$ and $\mu = 2{\cdot}0$, we find a negative value for y_s of about $-{\cdot}046$. This figure can of course have no meaning other than as showing that y_s is much reduced and a very large radius therefore implied. It is to be noticed that an infinite atmosphere with $\rho' \propto T'^{3\cdot25}$ would have a finite mass.

7. For stars of mass less than $5\odot$, the quantity $\bar{\alpha}$ varies with r and may be empirically represented as proportional to $\rho^{-\frac{1}{2}}T^{\frac{3}{4}}$. If this factor is included in the opacity the radiative equation takes the form

$$r^2\frac{dT}{dr} \propto -\rho^{1\cdot5}T^{-5\cdot75}$$

and the limiting effective index in the atmosphere is now 3·83. This results in changing (7) to

$$\frac{\mu(1-X^2)}{\mu'(1-X'^2)} = \frac{4{\cdot}83}{n(y_0)+1}. \qquad (7')$$

Since the lower limit of n is still 1·5 it is seen that a greater reduction of the temperature gradient is now possible. Although detailed numerical integrations would be necessary to establish the result it seems highly likely that in this case the conditions are more suitable for configurations of large radius.

8. So far it has been shown that a decrease in molecular weight may result in an increase in z_s. The unit of z however depends on the various parameters associated with a stellar configuration. These have been considered in a previous paper.* The only parameter appreciably affected by the change in μ involved here is m. The unit of z is proportional to

$$r_c \propto m^{\frac{2\eta-7}{2\eta+5}}$$

* *M.N.*, 102, 177, 1942.

in the notation of the paper cited, where η is the index of T appearing in the energy generation formula having a value of 17 ± 1. Hence if $\bar{M}$ now denotes the whole mass of the star in gms. we have from the above

$$r_c \propto (m/\bar{M})^{2/3} \bar{M}^{2/3}.$$

Now the fraction $m/\bar{M}$ has been shown to equal $(3M)^{-1}$ where M is the limiting value of $M(z)$ obtained by integrating equations (2). Hence

$$\text{unit of } z \propto (M)^{-2/3}$$

for stars of the same total mass but with different compositions in the exterior. Accordingly the unit of z is reduced owing to the change in the configuration, but it is readily seen that for the above cases this part of the effect on the actual radius is unimportant.

Thus in the first example $z_s = 17{\cdot}7$ and $M < 3{\cdot}35$. Since the standard configuration has $M = 3{\cdot}126$ it follows at once that measured in the same units as the standard configuration with the same total mass, the radius of this star is $> 16{\cdot}9$ units.

Similarly in the example in which $z_s = 24{\cdot}7$ and $M < 3{\cdot}61$, the radius in the same units is reduced slightly to $> 22{\cdot}5$ units.

Since the luminosity of the star is proportional to *

$$(m/\bar{M})^{\frac{10\eta+31}{2\eta+5}}$$

it follows that as compared with the luminosity of a star of the same total mass and with μ constant throughout, L would be decreased by a factor

$$\left\{\frac{M(\text{standard configuration})}{M(\text{giant configuration})}\right\}^{\frac{10\eta+31}{2\eta+5}}$$

For the first of the above examples this factor is about $4/5$, while for the second it is about $1/2$. Thus a star that happens to be in the giant state will have luminosity less than that of a star of the same mass and a uniform composition the same as that of the interior of the giant star. It would appear therefore that for stars of very great radius the reduction might amount to one or two magnitudes or even more.

9. The general trend of the above numerical examples shows that as the value of y_0 increases from 0·1435, the surface value of the standard configuration, the radius of the resulting composite configuration increases. This increase however cannot continue indefinitely and at some value for y_0 a maximum extension of radius must take place. For if the change in μ occurs almost at the centre of the star the value of z_s is unchanged, and therefore at some intermediate point or points a maximum extension of radius must occur.

Although the numerical results are based on approximations there seems no doubt that a decrease in μ in the outer part of the star will lead to a considerable increase in the actual radius. The simplification of changing μ abruptly does not introduce any serious limitation, for the effect of a continuous decrease according to some function such as $\mu \propto T^s$ over a finite range of y and T can easily be shown to involve no essential feature that could not be represented by a discontinuous change. The neglect of the contribution of the atmosphere to $M(z)$ is however more important and must be especially so for models for which y_s may tend to zero. To take full account of this however would require detailed integrations of the utmost accuracy.

10. Accepting the general conclusion arrived at above as indicative of what would occur in stars of non-uniform composition, we may discuss briefly the astronomical consequences of the analysis. In the first place it is to be noticed that the type of distribution required for obtaining large radius appears to be one in which the regions of

* *M.N.*, 102, 185, 1942.

lower μ contain only a minor part of the mass, say less than 25 per cent. The giant property occurs because what may be termed the atmospheric composition differs from that of the major part of the mass. In order that the present theory shall apply to actual stars some process must be available to produce the requisite change in μ. Two such processes appear to operate in the stars. In the first place there is the general synthesis of the elements which releases the stellar energy and in undisturbed conditions would presumably be accompanied by a steady increase in μ in the central core. The suggestion that a change in radius could be produced by having a star with a convective core of higher μ than the radiative exterior has been made by Öpik, but according to Wasiutynski the change in radius thereby produced is negligible. This is in general agreement with the findings of the present paper which indicate that large changes of radius occur through non-uniform composition of the atmosphere only.

The second process causing non-uniform composition is evidently that of accretion of hydrogen. An immediate advantage of this mechanism over the first is that it affects principally the atmosphere, at any rate to begin with. Moreover, the very existence of massive stars of ages of the order of 10^9 years shows that hydrogen must be added at sufficient rate to change the masses by an amount comparable with the whole mass in a period of this order. If we regard this as the cause of the change in the value of μ we can follow out in general terms the development of a star to the giant state.

Consider a star initially of uniform composition for which $\mu \sim 2$ throughout. It is generally agreed that more or less random slow circulatory currents exist tending to smooth away irregularities of composition and affecting a star as a whole in a time of the order of 10^7 years. Accordingly any giant character obtaining through inequalities of composition must probably be regarded as having a lifetime not in excess of this even if the only cause acting to destroy differences of composition were these random currents. The star may therefore be regarded as having standard radius with $z_s = 7$, together with a constant value of μ and a given mass. Addition of hydrogen at the surface will then result in an increase of z_s, the amount of this increase depending on the amount of superficial hydrogen. So long as the discontinuity in μ is such that a condition corresponding to (7) can be satisfied, redistribution of the material can occur only through the action of the slow circulatory currents and therefore the star could possess an abnormally large radius for a considerable time, possibly in excess of 10^6 years. If however the change in μ is so great that (7) can no longer be satisfied, then as has been seen there is no equilibrium state for the atmosphere. The reduction of μ'/μ to a value just below the limit 0·61 would render the atmosphere unstable, but it can scarcely be supposed that this would immediately involve any striking change in its general extent. If neither convective nor radiative equilibrium is possible the only situation remaining would seem to be some kind of dynamic state (but essentially different from mere convection currents which are not inconsistent with equilibrium) and it appears that some form of large scale motion must be set up. Presumably the amount by which μ'/μ comes to deviate from the limiting value would determine the degree of intensity with which any dynamical motions occurred. It is further evident that any such motions must operate to assist the redistribution of the material and thereby tend to bring the star back to a stable equilibrium state.

The analysis given refers to the case for which radiation pressure is negligible so that $n = 3/2$ in the core. It has been seen that the condition for large radius is more likely to occur the greater the difference between the value of n in the core and the limiting effective index in the atmosphere (usually 3·25). Accordingly it appears that the conditions are most favourable for stars of moderately small mass for which this difference tends to be largest. It is not altogether clear how the presence of appreciable radiation pressure might affect the problem, for it would hardly be satisfactory to discuss the matter on the basis of constant ratio of gas pressure to radiation pressure. The two cases that admit of relatively simple discussion are first that considered above when β differs

negligibly from unity and second when β is very near zero so that the whole distribution can be closely represented by the polytrope of index 3. In the latter case however the difference between the extreme values of n is so small that no important change of radius could occur through any non-uniformity of composition.

Summary

The solution of the equations governing the radiative equilibrium of the outer part of a star is considered first with a view to obtaining the accurate solution in the case of negligible radiation pressure and second to finding the error introduced by putting $\rho \propto T^{3.25}$ in the exterior.

By means of this approximation the radius of a star when the atmosphere has molecular weight less than in the interior can be calculated and it is found that a considerable increase of radius may result. It is also shown that a difference of composition of more than a certain amount leads to there being no equilibrium configuration available for the atmosphere. The causes leading to the conditions for giant stars and non-static atmospheres being brought about are briefly discussed.

The authors are indebted to the referee of the foregoing paper and of that entitled "On the Internal Constitution of the Stars" (of which the present investigation originally formed a part) who has offered many valuable suggestions during the preparation of these papers.

MAGNITUDES AND COLOURS OF O- AND EARLY B-TYPE STARS SOUTH OF −35° DECLINATION

The late E. G. Williams and H. Knox-Shaw

(Received 1942 June 4)

The work described in this paper was planned, and all the observations were made, by the late Gwyn Williams. The plates were measured by him, and he had made some progress with the reductions at the time of his death. These have been completed, following as far as possible the methods he had initiated. Some difficulty was, however, experienced in interpreting the notes left by Williams and in discovering exactly what he had done and intended to do.

Programme.—The programme comprised all the stars in the *Henry Draper Catalogue* south of −35° declination given as of type B3 or earlier and with photometric magnitudes brighter than 6·0 (except that two stars, HD 56733 and 132058, β Lup, were inadvertently omitted from the list), together with several stars further north to act as a comparison with the results of Stebbins and Huffer.* The number of stars observed was 157 south of −35° and 24 north of this limit. It was the observer's intention to take at least two plates of each star, but for one star in the main list and for eight of the more northern stars only a single satisfactory plate was obtained.

Methods of Observation.—The telescope used was the 7-inch finder of the uncompleted reflector. This is an old visual refractor with a focal length of 299 cm. Photographs were taken of each star through three filters, Wratten Nos. 35, 60 and 25, giving blue, green and red images, panchromatic plates being employed. The average number of stars on a plate was six, and the programme was arranged so that the stars on any one plate were taken at the same altitude to within a few degrees, thus minimising the differential corrections for atmospheric extinction. A graphical device, capable of giving the altitude to one degree of any star in the programme for a given sidereal time, was constructed by Williams to facilitate the rapid selection of stars to be included on one plate. As all the stars on a plate were given the same exposure for the same colour, it was necessary to limit the range in their brightness to about one magnitude. The plates were impressed with three sets of sensitometer spots, one through each filter. The sensitometer employed was one devised by Williams for this particular piece of work. It projected the light of a "daylight" lamp, diffused by ground glass and opal screens, through three sets of eight holes of graduated size, each set being covered by one of the colour filters. The three sets of sensitometer spots were thus impressed simultaneously on three corners of the plate. All the plates were brushed during development.

The early observations (the first 18 plates out of the 78 obtained) were made with extrafocal images. By a suitable choice of plane for the photographic plate it was possible to obtain red and green images of approximately equal size and similar appearance, but owing to the steep colour curve of the old 7-inch objective—the difference of focus for $\lambda\lambda$ 3500 and 5000, as subsequently determined by Redman, being 37 mm.—it was necessary to interpose a weak converging lens in front of the blue filter to render the blue image comparable in size with the other two. Even then it had a very different pattern. So for subsequent plates, at Redman's suggestion, a method due to Fabry was employed. In this method a small lens is inserted near the focus of the objective, and the image of the latter illuminated by the star is thus projected on to the plate. By this

* *Washburn Pub.*, 15, 217, 1934. The later paper, *Mt. Wilson Contr.*, 621, 1940, which was subsequently used, had not appeared at the inception of this work.

means disks quite uniform in density and of the same size for all three colours were obtained with the same setting of the plate. The lenses used were of focal lengths 13 and 8 mm., the latter being employed for the fainter stars. Diaphragms of 2, 1 or ½ mm. diameter were placed just in front of the lens to cut down the effect of sky illumination and the light from any near stars. The three colour filters were fixed in a circular brass disk mounted eccentrically in front of the small lens. By rotation of this disk either a clear aperture or any one of the filters could be quickly placed in the optical axis.

Measurement and Reduction.—The observatory's measuring machine by Casella was adapted to the measurement of the density of the stellar and sensitometer images by the addition of a photo-electric cell with one-valve amplifier and mirror galvanometer. The computed values of the magnitude differences of the sensitometer spots were corrected by a comparison with the brighter stars in the Pleiades, where the magnitude scale is well determined. Separate series of magnitude differences were adopted for each colour. Reduction curves were made by plotting these adopted magnitude differences against the densities of the sensitometer spots. A number of these curves were made for each make of plate—actually four kinds of panchromatic plates were used—and for each of the three colours, the grouping of the plates to form mean curves being according to their contrast. Using the most appropriate curve Williams then converted the density measures of the star images into units of 0·01 magnitude. These values were then corrected for differential atmospheric extinction. The adopted values for the extinction in the zenith, as determined from pairs of stars at different altitudes on four good nights, were 0·32, 0·21 and 0·15 magnitude for the three colours, blue, green and red. As the average value of the zenith distance at which the plates were taken was only 37° and the average range on a plate but 5°, the corrections for differential extinction were only a few hundredths of a magnitude, and it was considered satisfactory to employ the values of the extinction coefficients given above for all nights on which plates were taken.

Thus each plate furnished for the stars on that plate magnitudes with quite arbitrary zeros for each of the three colours. To determine the zeros Williams had taken seven plates connecting five of his stars with two of the Pleiades (No. 6, 19 Tau, HD 23338, and No. 8, 16 Tau, HD 23288). His intention seems to have been to find the magnitudes of all his stars in the three colours by means of this comparison of his five standard stars with the Pleiades, and thence through fifteen other stars, which were more frequently observed than the rest and could therefore be treated as secondary standards. The colours of the stars could also be found by another method, for the differences between the magnitudes, blue *minus* red and blue *minus* green, for each star on a plate give the colours of the stars referred to the mean colour of the stars on that plate.

Williams had brought the reductions to this stage, except for a few of the plates, at the time of his death.

The next step in the reduction was to determine the effective wave-lengths of the three colours. Williams had obtained photographs of three B stars and one K star through an objective grating of his own construction. The resulting effective wave-lengths were as follows:—

Effective Wave-lengths from Objective Grating

Type	Blue	Green	Red
B	4290	5140	6160
K	4480	5280	6200

The values for the blue seemed too high, and when it was realised how steep was the colour curve of the objective it appeared that some of the shorter blue light must have been ineffective owing to its being so much out of focus. This view was confirmed by the high value, viz. λ 4710, found by Redman when using the grating on two stars, of

types B5 and A8, with an Ilford Zenith plate without a filter. An attempt was therefore made to *calculate* the effective wave-lengths. The data employed were:

(*a*) The relative intensities at different wave-lengths of the black-body spectrum for temperatures of 20,000° and 4560° assumed to be representative of B and K stars. These were taken from the *Handbuch der Astrophysik.*

(*b*) The atmospheric extinction at different wave-lengths. From the figures in the *Handbuch* those for Mt. Wilson were selected as being most likely to fit Pretoria.

(*c*) The transmission of the 7-inch objective. This was determined by Redman with the Cambridge eclipse spectrograph. Despite the green appearance of the glass it was found that the percentage transmission at λ 3600 is as high as 16. It rises to a maximum of 87 at λ 5000 and then falls slowly to 70 at λ 6500.

(*d*) The transmission of the filters. The values supplied by the makers were used, taking account of the absorption of the cover glass for light shorter than λ 4000.

By multiplying together these four factors we obtain the relative intensity of the light reaching the photographic plate. The figures are given in Table I.

TABLE I

Relative Intensity of Light transmitted through Atmosphere, Objective and Filters

Filter / Wave-length	$T=20{,}000°$ (B Star)			$T=4560°$ (K Star)			Filter / Wave-length	$T=20{,}000°$ (B Star)			$T=4560°$ (K Star)		
	35 Blue	60 Green	25 Red	35 Blue	60 Green	25 Red		35 Blue	60 Green	25 Red	35 Blue	60 Green	25 Red
3500	1						5300		43			54	
3600	5			1			5400		35			48	
3700	11			2			5500		26			37	
3800	22			5			5600		16			24	
3900	36			10			5700		8			13	
4000	55			17			5800		4			7	
4100	65			24			5900		1	5		2	10
4200	60			26			6000			23		1	47
4300	47			23			6100			30			66
4400	31			17			6200			33			76
4500	17			11			6300			33			79
4600	7	2		5	2		6400			31			80
4700	1	9		1	7		6500	1		30	2		81
4800		20			16		6600	5		29	13		81
4900		34			31		6700	10		28	30		82
5000		47			46		6800	15		27	45		82
5100		52			55		6900	17		26	54	1	82
5200		48			56		7000	18	1	25	59	2	81

We had finally to obtain values for the plate sensitivity. No quantitative figures were available for the plates actually employed, but a spectrum test by Redman on an Ilford Hypersensitive Panchromatic plate—one of those used by Williams—showed that its sensitivity dropped sharply above λ 6400 and was very small indeed beyond λ 6600. Effective wave-lengths were therefore computed on the assumption that the sensitivity was uniform from λ 3500 to λ 6500 and zero beyond that point. Figures given in *Lund Annals*, 7, 1938, for the sensitivity of this same plate were also employed to provide alternative values. Table II gives the results of these two calculations together with those derived from the grating plates and the values finally adopted.

TABLE II

Effective Wave-lengths

Method	B Star			K Star		
	Blue	Green	Red	Blue	Green	Red
Grating,	4290	5140	6160	4480	5280	6200
Constant sensitivity	4130	5180	6250	4230	5230	6270
Lund sensitivity	4050	5130	6270	4120	5200	6290
Adopted values	4100	5150	6200	4250	5250	6250

It was now necessary to determine magnitudes at each of the three wave-lengths for the stars Nos. 6 and 8 in the Pleiades. Hertzsprung's photographic magnitudes for these stars, viz. 4·18 and 5·37, were adopted, and it has been assumed that these refer to an effective wave-length of λ 4190.* Stebbins's colour indices for these two stars, reduced to the International system by multiplying by 1·50 †, viz. $-0^m\cdot21$ and $-0^m\cdot17$, were also adopted, and it has been assumed that the effective wave-length of the International Photovisual system is λ 5330. The various values found in published papers for wave-lengths of photographic and photovisual magnitudes could not be reconciled, and the value λ 5330 was deduced from the value λ 5420 for the Harvard Photovisual system ‡ and the equation connecting International with Harvard *Pv* magnitudes, viz. $IPv = HPv + 0^m\cdot10 + 0\cdot06\ CI$.§ With these assumptions and by simple interpolation in $1/\lambda$ the magnitudes of the two Pleiades at the three adopted wave-lengths were found to be:

Adopted Magnitudes of Pleiades Stars

Colour	Blue	Green	Red
Effective λ	4100	5150	6200
	m	m	m
Pleiades No. 6	4·16	4·36	4·50
Pleiades No. 8	5·35	5·52	5·63

From these values magnitudes were found for the five standard stars and thence, by comparison from plate to plate, for all the stars contained in the programme. This procedure was not as satisfactory as had been hoped, as the fifteen stars selected as secondary standards had not all been directly connected with the five standard stars, and there were even a number of plates that did not contain any of these twenty standards. Thus the determination of the magnitudes of some of the stars had to be effected by rather roundabout ways involving the possibility of accumulation of errors. From the blue, green and red magnitudes thus found photographic and photovisual magnitudes have been derived by simple interpolation, and thence colour indices on the International system. This procedure is probably quite satisfactory for the normal B stars, but seems less so for the emission stars and those with marked colour excess.

The colours of the stars have also been found by the alternative method already mentioned. The magnitude differences, blue *minus* red and blue *minus* green, given by each plate, afford measures of the colour of each star relative to the mean colour of the stars on that plate. These values were listed after all stars having obvious colour excess had been rejected from the plate-means, and mean provisional values of the colours, blue *minus* red and blue *minus* green, were formed for each star. By means of these values corrections were found for each plate, which when applied to the stars on that plate made the colours already found relative to the mean of all the stars observed, excluding only those with definite colour excess, hereinafter referred to as the "red" stars. It is clear, however, that owing to the small number of stars on a plate this method tends

* *H.C.*, 404, p. 14, 1935.
† *Mt. Wilson Contr.*, 621, 1940.
‡ *H.C.*, 404, p. 14, 1935.
§ *H.A.*, **89**, 199, 1938.

to make the derived colours more uniform than they really are, except in the case of the "red" stars, which were not included in the plate-means. The final reduction from colours relative to the mean of all the stars observed to "absolute" colours was found by comparing the colours of the five standard stars as given by the above method with those derived from their magnitudes determined from the comparison with the Pleiades. The values of the correction given individually by the five stars were reasonably accordant. A check on the mean value was afforded by comparing the colour indices formed in this way, C_c, with those of Stebbins, for the 24 stars common to the two lists. In the mean the agreement was within 0·01 magnitude. The colour indices, C_m, found by the first method, *i.e.* from the photographic and photovisual magnitudes, agreed in the mean almost as well with Stebbins's values, but individually the accordance was not so good, from which fact it appears that their weight is only about half that of those found by the alternative method. The agreement between the two sets of colour indices, C_c and C_m, for the 181 stars is satisfactory except in the case of the "red" stars, as Table III indicates.

TABLE III

Comparison of Colour Indices derived by the Two Methods

C_c	No. of Stars	C_c Mean	C_m Mean
m m		m	m
−·37 to −·31	57	−·33	−·34
−·30 ,, −·26	62	−·28	−·28
−·25 ,, −·21	32	−·24	−·24
−·20 ,, −·16	10	−·19	−·16
−·15 ,, −·01	9	−·12	−·05
·00 ,, +·31	11	+·11	+·20

All the stars in the last group and all but two of those in the penultimate group were recognised as having colour excess and were not included in the plate-means for determining relative colours. Thus the smaller excess shown by the mean value C_c for these two groups cannot be accounted for by the levelling process inevitable in this method of determining colours when there are only a comparatively few stars on each plate. No reason has been found for the apparently systematic difference between C_c and C_m for the stars of high colour. The adopted values, CI, are the means of C_c and C_m, giving the former double weight.

The Results.—The results of the observations appear in Table IV. The successive columns give the HD number of the star; its name; its type as revised at Victoria or that of the HD, in italics, when the former is not available; the observed magnitudes in the three colours, and the deduced photographic and photovisual magnitudes, the adopted effective wave-length being given at the top of each column; a comparison of the photovisual magnitude with that of Harvard, in the sense Williams *minus* Harvard, employing (*a*) the magnitudes given in the Harvard Mimeograms reduced to the International system and (*b*) revised values of which mention will be made later; values of the colour index, C_c and C_m, found by the two methods already described; and the adopted colour index, $CI=(2C_c+C_m)/3$. The stars in the main programme, those south of $-35°$, and those further north, observed to afford a comparison with Stebbins's results, appear in separate sections of the table. The latter were not so fully observed. The table is followed by remarks on certain of the stars, attention to the remarks being called by an asterisk in the table.

One of the difficulties involved in observations of this kind is caused by the presence of companions, even fairly distant ones. Williams examined the stars visually before photographing them, and his notes contain references to the presence of other stars near enough and bright enough to affect the observed magnitudes. It can be taken for granted that when there is another star at a distance of less than 20″ the combined magnitude

TABLE IV

Stars South of −35°

HD	Name	Type	Observed Magnitudes					(Unit 0·01 Mag.)				
			B 4100	G 5150	R 6200	*Pg* 4190	*Pv* 5330	W. – Harv. H.M.	W. – Harv. Rev.	C_c	C_m	*CI*
28873	δ Cæ	B3s	4·85	5·13	5·28	4·88	5·16	0	− 4	−32	−28	−31
40494	γ Col	B3	4·13	4·46	4·60	4·16	4·49	+ 5	+ 7	−29	−33	−30
42933	δ Pic	B1n	4·47	4·81	4·98	4·50	4·84	+ 3	+ 4	−37	−34	−36
54893	A Pup	B3s	4·68	4·95	5·12	4·71	4·98	+ 7	+13	−28	−27	−28
56779		B3	4·84	5·13	5·33	4·87	5·17	+ 7	+13	−31	−30	−31
57150	v^1 Pup	B3ne	4·67	4·87	4·99	4·69	4·89	+13	+10	−23	−20	−22
57219	v^2 Pup	B3	4·89	5·19	5·38	4·92	5·23	+ 1	+ 1	−30	−31	−30
61831	d^1 Pup	B3n	4·54	4·81	5·04	4·57	4·86	−15	− 3	−28	−29	−28
61925		B5n	5·75	6·01	6·13	5·78	6·03	− 2	+ 5	−24	−25	−24
62226		B3	5·18	5·46	5·63	5·21	5·49	− 4	0	−28	−28	−28
63465		B3	4·94	5·20	5·33	4·97	5·23	+ 4	+ 2	−27	−26	−27
63578		B2	5·07	5·31	5·48	5·09	5·34	+ 8	+ 6	−27	−25	−26
63922	P Pup	B0	3·78	4·13	4·36	3·82	4·18	− 7	+ 1	−30	−36	−32
63949		B2	5·52	5·79	5·95	5·55	5·82	−13	− 9	−27	−27	−27
64503	*b* Pup	B3	4·23	4·51	4·75	4·26	4·56	− 6	+ 1	−28	−30	−29
64722		*B3*	5·52	5·68	5·82	5·54	5·71	−11	− 8	−27	−17	−24
64740		B3n	4·40	4·66	4·91	4·43	4·71	− 8	− 6	−28	−28	−28
64760	J Pup	B2n	3·97	4·26	4·50	4·00	4·31	+ 3	+ 5	−24	−31	−26
64802		B5	5·23	5·52	5·67	5·26	5·55	+ 7	+ 9	−32	−29	−31
65460		B3	5·09	5·44	5·59	5·13	5·47	+ 3	− 2	−34	−34	−34
65551	N Pup	B3s	4·87	5·20	5·30	4·90	5·22	+ 9	+11	−29	−32	−30
65575	χ Car	B3	3·29	3·60	3·84	3·32	3·65	+ 9	+12	−27	−33	−29
65818*	V Pup	B2n	4·13	4·41	4·69	4·16	4·47	0	+ 3	−27	−31	−28
66194		B5n	5·74	5·84	5·92	5·75	5·86	+ 1	+ 2	−22	−11	−18
66591	D Car	B3s	4·73	4·92	5·07	4·75	4·95	+ 2	+ 4	−26	−20	−24
66811	ζ Pup	O8nek	1·99	2·31	2·69	2·02	2·39	+ 4	+15	−34	−37	−35
68217		B3	4·91	5·33	5·48	4·95	5·36	+18	+14	−35	−41	−37
68243	γ^1 Vel	B3n	4·06	4·39	4·60	4·09	4·43	−32	−28	−35	−34	−35
68273	γ^2 Vel	OW9k	1·54	1·88	2·30	1·57	1·96	−22	+12	−35	−39	−36
68324		B3n	4·97	5·29	5·44	5·00	5·32	− 4	− 1	−33	−32	−33
68657		B3	5·52	5·79	6·02	5·55	5·84	− 6	− 3	−30	−29	−30
68980	*r* Pup	B3ne	4·42	4·65	4·85	4·44	4·69	−10	−10	−22	−25	−23
69081		B3n	4·88	5·17	5·37	4·91	5·21	+ 4	+ 5	−30	−30	−30
69144		B5	4·87	5·22	5·37	4·91	5·25	+ 1	+ 5	−28	−34	−30
69302		B3	5·55	5·83	6·00	5·58	5·86	−12	− 9	−32	−28	−31
70556		B3	4·84	5·25	5·46	4·88	5·29	+11	+ 6	−35	−41	−37
70930	B Vel	B2n	4·52	4·82	5·00	4·55	4·86	− 1	+ 3	−27	−31	−28
71459		B3	5·30	5·53	5·72	5·32	5·57	+24	+13	−25	−25	−25
71510*		B3n	4·87	5·21	5·35	4·90	5·24	+ 5	+ 9	−27	−34	−29
72067		B3n	5·52	5·81	6·03	5·55	5·85	− 5	− 2	−32	−30	−31
73390		B3	5·12	5·31	5·44	5·14	5·34	− 2	+ 2	−29	−20	−26
74195	*o* Vel	B3	3·21	3·60	3·89	3·25	3·66	+ 2	+ 6	−28	−41	−32
74375	*d* Car	B1s	4·21	4·46	4·59	4·24	4·49	+11	+15	−26	−25	−26
74455		B3nk	5·20	5·55	5·72	5·24	5·58	+13	+17	−30	−34	−31
74753	D Vel	B3n	4·89	5·21	5·37	4·92	5·24	+ 9	+13	−31	−32	−31
75311*	*f* Car	B3n	4·09	4·51	4·67	4·13	4·54	− 5	− 2	−28	−41	−32
75821	*f* Vel	B0	4·67	5·14	5·31	4·72	5·17	+ 1	+ 4	−34	−45	−38
76538		B5	5·66	5·77	5·89	5·67	5·79	−16	−12	−23	−12	−19
77002	b^1 Car	B5	4·80	5·00	5·14	4·82	5·03	+ 2	+ 3	−31	−21	−28
78764	E Car	B3ne	4·58	4·82	4·90	4·60	4·84	+ 1	+ 3	−26	−24	−25
79275		B3s	5·57	5·81	6·03	5·59	5·85	− 3	− 1	−32	−26	−30
79351	*a* Car	B3s	3·10	3·48	3·77	3·14	3·54	+ 3	+ 5	−29	−40	−33

TABLE IV—*Continued*

HD	Name	Type	Observed Magnitudes					(Unit 0·01 Mag.)				
			B 4100	G 5150	R 6200	*Pg* 4190	*Pv* 5330	W.–Harv. H.M.	W.–Harv. Rev.	C_c	C_m	*CI*
79447	*i* Car	B3	3·82	4·09	4·28	3·85	4·13	− 1	+ 2	−28	−28	−28
79735	$\varkappa$ Vel	B5n	4·98	5·25	5·41	5·01	5·28	+11	+ 3	−30	−27	−29
81188	κ Vel	B3	2·20	2·54	2·86	2·23	2·60	+ 1	+ 4	−29	−37	−32
82984		B3n	4·95	5·18	5·32	4·97	5·21	−10	− 8	−27	−24	−26
83058	L Vel	B3n	4·77	5·07	5·23	4·80	5·10	− 2	+ 1	−29	−30	−29
83979	ζ Cha	B3	4·89	5·12	5·28	4·91	5·15	− 6	− 4	−25	−24	−25
84816		B5	5·30	5·55	5·74	5·33	5·59	−11	−16	−32	−26	−30
85953		B3s	5·71	5·91	6·10	5·73	5·95	− 1	+ 2	−32	−22	−29
92938		B3	4·70	4·92	5·01	4·72	4·94	−23	−22	−27	−22	−25
92964*		B1s	5·50	5·44	5·37	5·49	5·43	0	+ 3	+ 5	+ 6	+ 5
93030	θ Car	B0n	2·50	2·81	3·14	2·53	2·88	−11	−10	−30	−35	−32
93194		B3nn	4·72	4·92	5·02	4·74	4·94	−12	−11	−23	−20	−22
93845	δ^2 Cha	B5	4·29	4·59	4·75	4·32	4·62	+ 4	+ 4	−32	−30	−31
96706		*B3*	5·40	5·64	5·74	5·42	5·66	− 8	−10	−29	−24	−27
97670		B3s	5·63	5·73	5·84	5·64	5·75	−17	−19	−24	−11	−20
99264		*B3*	5·48	5·60	5·63	5·49	5·61	− 2	− 5	−17	−12	−15
100929		*B3*	5·70	5·84	5·96	5·71	5·86	+ 8	+ 6	−26	−15	−22
104841	θ^2 Cru	B3	4·61	4·72	4·86	4·62	4·75	−13	−20	−20	−13	−18
105435	δ Cen	B3nne	2·45	2·82	3·01	2·49	2·86	+ 5	+ 3	−25	−37	−29
105521		B3	5·30	5·57	5·71	5·33	5·60	− 2	−12	−30	−27	−29
105937	ρ Cen	B3n	3·68	4·09	4·30	3·72	4·13	− 1	− 3	−30	−41	−34
106231		B5	5·41	5·72	5·86	5·44	5·75	−19	−18	−33	−31	−32
106490	δ Cru	B3	2·43	2·89	3·18	2·48	2·95	− 6	− 8	−34	−47	−38
106983	ζ Cru	B3	3·83	4·25	4·37	3·87	4·27	+ 8	+ 7	−36	−40	−37
108248	α^1 Cru	B1n	0·47	0·90	1·14	0·51	0·95	− 3	− 5	−36	−44	−39
108249	α^2 Cru	B3n										
108257	G Cen	B3n	4·36	4·80	4·94	4·40	4·83	−15	−16	−30	−43	−34
108483	σ Cen	B3n	3·54	4·03	4·21	3·59	4·07	− 2	− 4	−33	−48	−38
109668	α Mus	B5nn	2·51	2·81	3·09	2·54	2·87	0	− 1	−22	−33	−26
110432		B1nne	5·52	5·46	5·25	5·51	5·42	−54	−58	+ 7	+ 9	+ 8
110879	β Mus	B3	2·72	3·12	3·42	2·76	3·18	− 2	− 3	−28	−42	−33
110956		B5s	4·54	4·77	4·94	4·56	4·80	+ 1	− 1	−29	−24	−27
111123	β Cru	B1s	0·97	1·37	1·62	1·01	1·42	− 1	− 3	−35	−41	−37
112078	λ Cru	B3n	4·34	4·63	4·84	4·37	4·67	−11	−12	−32	−30	−31
112091	μ^2 Cru	B3ne	3·51	3·78	4·04	3·54	3·83	− 5	− 7	−24	−29	−26
112092	μ^1 Cru	B3										
112244		O9	5·21	5·31	5·37	5·22	5·32	−21	−22	−14	−10	−13
113120		B3nne	5·82	5·92	5·91	5·83	5·92	+ 2	+ 1	−14	− 9	−12
113703	*f* Cen	B3n	4·45	4·73	4·82	4·48	4·75	−15	−16	−22	−27	−24
113791	ξ^2 Cen	B3	3·97	4·33	4·48	4·01	4·36	+ 2	0	−31	−35	−32
113904*	θ Mus	B0e	5·45	5·63	5·65	5·47	5·63	+ 6	+ 3	−23	−16	−21
115823		B8	5·16	5·44	5·56	5·19	5·46	−17	−19	−30	−27	−29
118716	ϵ Cen	B2n	2·07	2·43	2·78	2·11	2·50	+ 1	− 1	−33	−39	−35
120307	ν Cen	B2	3·20	3·53	3·81	3·23	3·59	+ 5	+ 5	−31	−36	−33
120324	μ Cen	B3ne	3·11	3·39	3·57	3·14	3·43	+10	+ 4	−21	−29	−24
120640		B3s	5·44	5·72	5·86	5·47	5·75	− 5	−10	−31	−28	−30
120991		B3se	5·62	5·84	5·91	5·64	5·85	− 3	+ 4	−24	−21	−23
121263	ζ Cen	B3	2·23	2·55	2·92	2·26	2·62	−42	−14	−29	−36	−31
121743	ϕ Cen	B3	3·56	3·86	4·10	3·59	3·91	−13	− 9	−31	−32	−31
121790	υ^1 Cen	B3n	3·59	3·92	4·15	3·62	3·97	−20	− 5	−35	−35	−35
122451	β Cen	B3	0·43	0·74	0·98	0·46	0·79	− 1	− 2	−27	−33	−29
122980	χ Cen	B3s	4·11	4·41	4·57	4·14	4·44	−11	−16	−32	−30	−31
124367		B3nne	4·87	5·12	5·16	4·90	5·13	−16	− 1	−20	−23	−21
124471		B2s	5·55	5·73	5·83	5·57	5·75	−22	−10	−26	−18	−23

TABLE IV—*Continued*

HD	Name	Type	Observed Magnitudes					(Unit 0·01 Mag.)				
			B 4100	G 5150	R 6200	*Pg* 4190	*Pv* 5330	W.–Harv. H.M.	W.–Harv. Rev.	C_e	C_m	CI
125238	ι Lup	B3nn	3·14	3·58	3·78	3·18	3·62	−48	−18	−36	−44	−39
126341	τ^1 Lup	B3	4·24	4·57	4·74	4·27	4·60	− 3	− 2	−32	−33	−32
127381	σ Lup	B3	4·16	4·50	4·65	4·19	4·53	0	− 1	−30	−34	−31
127972*	η Cen	B3ne	2·18	2·44	2·83	2·21	2·52	− 9	− 2	−24	−31	−26
129056	α Lup	B2s	2·08	2·35	2·72	2·11	2·42	−42	− 6	−25	−31	−27
129116	b Cen	B3	3·73	4·02	4·22	3·76	4·06	− 8	−10	−29	−30	−29
131492	θ^1 Cir	B3n	5·18	5·40	5·50	5·20	5·42	+ 7	+ 6	−28	−22	−26
132200	κ Cen	B2s	2·94	3·28	3·56	2·97	3·34	− 2	− 1	−29	−37	−32
133955	λ Lup	B3	3·81	4·08	4·28	3·84	4·12	−25	−15	−31	−28	−30
134687	e Lup	B5	4·37	4·78	4·91	4·41	4·81	−13	−12	−32	−40	−35
135160*		*B1*	5·51	5·75	5·84	5·53	5·77	−11	− 8	−32	−24	−29
135240	δ Cir	O8n	4·95	5·16	5·27	4·97	5·18	+ 1	+ 1	−28	−21	−26
135591		O9s	5·25	5·50	5·60	5·28	5·52	+ 8	+ 8	−28	−24	−27
136298	δ Lup	B3n	2·91	3·36	3·55	2·96	3·40	− 1	+ 3	−33	−44	−37
136504	ϵ Lup	B3	3·19	3·56	3·75	3·23	3·60	−13	+ 5	−32	−37	−34
136664	ϕ^2 Lup	B3	4·36	4·63	4·82	4·39	4·67	− 7	− 6	−32	−28	−31
138690	γ Lup	B3	2·52	2·92	3·16	2·56	2·97	+ 1	+ 2	−28	−41	−32
138769	d Lup	B3	4·31	4·56	4·79	4·34	4·61	−21	−11	−31	−27	−30
143118	η Lup	B3n	3·13	3·49	3·76	3·17	3·54	−10	−17	−34	−37	−35
144294	θ Lup	B3n	4·02	4·35	4·58	4·05	4·40	+ 5	+ 3	−35	−35	−35
148379		B1s	5·98	5·54	5·17	5·91	5·47	+ 4	+ 5	+31	+44	+35
148688		B1	5·70	5·41	5·18	5·66	5·36	−14	−11	+16	+30	+21
149038	μ Nor	O9s	4·99	5·02	5·01	4·99	5·02	−16	− 5	− 7	− 3	− 6
149404		O9s	5·84	5·54	5·31	5·80	5·49	−12	− 3	+19	+31	+23
150135 } 150136 }	*	*Oe5*	5·53	5·43	5·30	5·52	5·40	−14	−13	+ 3	+12	+ 6
150168		*B1p*	5·50	5·67	5·74	5·52	5·68	−17	−16	−25	−16	−22
150742		B3n	5·50	5·60	5·66	5·51	5·61	− 9	− 9	−25	−10	−20
150745		B3	5·69	5·75	5·80	5·70	5·76	−12	−11	−25	− 6	−19
150898		Bon	5·46	5·63	5·68	5·48	5·64	− 5	− 4	−34	−16	−28
151804		O9e	5·23	5·27	5·21	5·23	5·26	−12	−10	−16	− 3	−12
151890*	μ^1 Sco	B3nn	2·77	3·14	3·48	2·81	3·21	− 1	− 1	−33	−40	−35
151985	μ^2 Sco	B2	3·35	3·69	3·97	3·38	3·75	0	+ 4	−34	−37	−35
152234		Bo	5·64	5·39	5·21	5·60	5·35	+ 5	+ 9	+ 5	+25	+12
152236	ζ^1 Sco	B1se	5·36	5·01	4·72	5·30	4·95	+ 3	+ 8	+31	+35	+32
152249		Bosk	6·56	6·35	6·17	6·53	6·31	+34	+38	0	+22	+ 7
152408		*Oep*	5·94	5·85	5·63	5·93	5·81	−17	−16	0	+12	+ 4
153716		B5	5·68	5·73	5·80	5·69	5·74	− 9	− 8	−28	− 5	−20
156838		B3s	5·48	5·66	5·74	5·50	5·68	−13	−10	−33	−18	−28
157042	ι Ara	B3nne	5·07	5·26	5·36	5·09	5·28	−15	−14	−29	−19	−26
157246	γ Ara	B1nn	3·06	3·38	3·64	3·09	3·43	− 1	0	−25	−34	−28
158408	υ Sco	B3	2·37	2·77	3·10	2·41	2·84	+ 2	+ 6	−33	−43	−36
158427	α Ara	B3ne	2·63	2·97	3·14	2·66	3·00	+10	+11	−22	−34	−26
158926	λ Sco	B2n	1·35	1·78	2·05	1·39	1·83	+ 9	+ 5	−34	−44	−37
160578	κ Sco	B3	2·04	2·44	2·79	2·08	2·51	+11	− 8	−34	−43	−37
161783*		B3s	5·52	5·61	5·72	5·53	5·63	−21	−17	−28	−10	−22
165024	θ Ara	B1	3·50	3·78	3·97	3·53	3·82	− 2	− 1	−25	−29	−26
166596		B3	5·25	5·47	5·60	5·27	5·50	− 3	−12	−28	−23	−26
168905		B5n	4·94	5·18	5·37	4·96	5·22	−20	−14	−37	−26	−33
169467	α Tel	B6	3·13	3·57	3·79	3·17	3·61	−15	− 5	−29	−44	−34
172910		B5	4·71	4·95	5·11	4·73	4·98	+ 8	+ 8	−29	−25	−28
173948	λ Pav	B3n	3·79	4·01	4·09	3·81	4·03	−34	−32	−22	−22	−22
189103	θ^1 Sgr	B5	4·20	4·47	4·64	4·23	4·50	+ 3	− 2	−32	−27	−30
193924	α Pav	B3s	1·81	2·06	2·35	1·84	2·12	+ 6	+10	−19	−28	−22

TABLE IV—*Continued*

Stars North of $-35°$

HD	Name	Type	Observed Magnitudes (Unit 0·01 Mag.)								
			B 4100	G 5150	R 6200	*Pg* 4190	*Pv* 5330	W.–Harv. H.M.	W.–Harv. Rev.	C_c	C_m	*CI*
45725	β Mon A	B3ne										
45726	β Mon B	B3	3·88	4·13	4·20	3·91	4·14	+11	+13	−30	−23	−28
45727	β Mon C	B3e										
53974*		B2n	5·44	5·45	5·44	5·44	5·45	+ 7	+ 8	−15	− 1	−10
74280	η Hya	B5n	4·04	4·34	4·57	4·07	4·39	− 5	− 3	−31	−32	−31
83754	κ Hya	B3	4·48	4·96	5·28	4·53	5·02	−12	− 7	−34	−49	−39
90994	30 Sex	B8	4·73	5·03	5·28	4·76	5·08	+ 1	+16	−31	−32	−31
91316	ρ Leo	Bosk	3·50	3·82	4·09	3·53	3·87	+ 2	−10	−24	−34	−27
129956	108 Vir	*B9*	5·61	5·71	5·79	5·62	5·73	+ 4	+19	−17	−11	−15
138764		B8s	5·01	5·23	5·29	5·03	5·24	− 1	+ 4	−28	−21	−26
142983	48 Lib	B3n	4·74	4·95	5·08	4·76	4·98	+26	+29	−24	−22	−23
149757	ζ Oph	Bonnk	2·56	2·54	2·82	2·56	2·60	−13	−12	+ 2	− 4	0
154445		B3k	5·72	5·76	5·68	5·72	5·74	+ 6	+ 9	−14	− 2	−10
163472		B2	5·83	5·81	5·77	5·83	5·80	− 1	0	−14	+ 3	− 8
164284	66 Oph	B5n	4·67	4·87	5·01	4·69	4·90	+ 6	+ 1	−25	−21	−24
164353*		B8s	4·05	4·16	4·30	4·06	4·19	+23	+22	−10	−13	−11
169033		*B8*	5·57	5·71	5·77	5·59	5·72	− 2	+ 1	−20	−13	−18
170740		B3k	5·88	5·91	5·75	5·88	5·88	+12	...	− 4	0	− 3
175191	σ Sgr	B3n	1·94	2·17	2·46	1·97	2·23	+ 7	+14	−18	−26	−21
176162		B7	5·41	5·56	5·66	5·44	5·58	+ 9	+ 9	−20	−14	−18
184915	κ Aql	Bonk	4·99	5·07	5·14	5·00	5·08	− 4	− 1	−14	− 8	−12
184930	ι Aql	B8n	4·27	4·49	4·58	4·29	4·51	+28	+16	−24	−22	−23
195810	ε Del	B7	3·82	4·08	4·31	3·85	4·13	+ 9	+ 4	−22	−28	−24
209409	o Aqr	B5ne	4·64	4·81	4·90	4·66	4·83	+23	+14	−20	−17	−19
214923	ζ Peg	*B8*	3·12	3·45	3·66	3·15	3·49	−10	+10	−22	−34	−26
219688	ψ^2 Aqr	B5n	4·25	4·51	4·65	4·28	4·54	− 6	− 4	−29	−26	−28

TABLE IV. REMARKS

Stars South of $-35°$

65818. Eclipsing Variable; observed magnitudes are reduced to mean, assumed as 0·40 brighter than principal minimum for all colours.

71510. Double Star, $5^m·2–8^m·8$, 26″. Williams's is combined magnitude; Harvard probably that of brighter star only; correction $0^m·04$.

75311. Mount Wilson type B3ne.

92964. Mount Wilson type B1se.

113904. Payne in *The Stars of High Luminosity* gives type as O9.

127972. HD gives spectrum as composite, B3p +A2p.

135160. Mount Wilson type B1e.

150135. } Multiple Star, $5^m·6–8^m·6$, 1″·7; $-7^m·1$, 10″; $-9^m·6$, 13″; +fainter companions. There
150136. } is some confusion in the Harvard volumes. HD gives 7·12 and 5·59 as the separate magnitudes of the two stars (150135, 6), but it seems that 5·59 should be the combined magnitude (see Remarks in HD and *H.A.*, 64, 174). Harvard Mimeogram assumes this is so. The companion at 13″ is probably also included in the Harvard magnitude, as in Williams's.

151890. Eclipsing Variable; observed magnitudes are reduced to mean, assumed as 0·20 brighter than principal minimum for all colours.

161783. Double Star, $5^m·9–9^m·5$, 12″. Harvard probably also gives the combined magnitude; correction would be $0^m·04$.

Stars North of $-35°$

53974. Double Star, $6^m.3$–$7^m.5$, $0''.6$; -9^m, $17''$. Harvard probably also gives combined magnitude; correction would be $0^m.07$.

164353. Double Star, $5^m.0$–$9^m.0$, $55''$. Williams's is combined magnitude; Harvard apparently that of brighter star; correction $0^m.03$.

of these two stars has been observed. Such seems usually also the case with the Harvard magnitudes, except when both stars are of about equal brightness and individual magnitudes have been determined with the double-image photometer. Attention is drawn in the Remarks to the few cases which admit of any doubt. The amount at issue is never at all large.

The ten stars with positive colour indices are all within 3° of the galactic plane and are situated in regions where there are signs of extensive obscuration, eight of them being in or near the southern part of Scorpio.

Comparison with Harvard Magnitudes.—Williams's *Pv* magnitudes were first compared with the values of the Harvard Mimeograms reduced to the International system by application of the correction $+0^m.10+0.06\ CI$. It was noticed that, although in the mean the agreement was good, there were several large divergences; in fact there were 19 stars with differences greater than 0.20 magnitude. This led to a scrutiny of the results from the catalogues in the various *Harvard Annals*, which were combined to form the Harvard Photometric system, as given in the *Revised Harvard Photometry* and the *Henry Draper Catalogue*, and on which the Harvard Photovisual system of the Mimeograms depends. And it was discovered that the observations of stars south of $-35°$ declination which had been made at Cambridge, Mass., had been included with those made in Peru. Of the 33 stars in Williams's list culminating at Cambridge at true altitudes of less than 5°, 24 had been observed there and the results incorporated in the mean magnitudes with those from the southern station, each catalogue being given equal weight.* The fact that it was possible to make observations at such low altitudes speaks well for the climate of Cambridge fifty years ago, but naturally some of the results are very discordant, and according to modern standards must be regarded as unreliable.

So a complete revision was made of the magnitudes of all the stars in the *Revised Harvard Photometry* south of $-30°$ declination, using only the observations made in the southern hemisphere. This revision also included a new determination of the systematic differences between the southern catalogues (*H.A.*, **34**, **46** and **64**) and the Harvard visual system embodied in *H.A.*, **44** and **45**, using only stars between the equator and $-30°$ declination for this purpose. The comparison between Williams's *Pv* magnitudes and these revised Harvard values shows only eight stars with differences greater than 0.20 magnitude instead of nineteen. The systematic differences are also slightly improved, as can be seen in Table V. They are really remarkably small considering that in the derivation of Williams's *Pv* magnitudes no Harvard results have been used. The only really large difference still remaining is that of HD 110432, which is a peculiar star with variable velocity shown by its emission lines. The Harvard observations of this star are consistent and provide no evidence of variation in brightness, but it is situated in the Coal Sack, and in the past forty years its magnitude may have changed owing to shifting of the obscuring matter; it has considerable colour excess. Of the other two stars with differences greater than 0.3 magnitude (HD 152249 and 173948, λ Pav), the former is also reddish and is situated in an obscured region, being involved in the cluster N.G.C. 6231. λ Pavonis seems a normal star, and no reason can be found for the discrepancy.

* The statement in *H.A.*, **50**, 1908, that the observations of γ^1 and γ^2 Vel (HR 3206, 7), made at Cambridge at a true (unrefracted) altitude of 0° 35′, had been rejected is not true. The good intention was not carried out.

TABLE V

Comparison with Harvard Magnitudes

(*a*) Between Williams's *Pv* magnitudes and Harvard Mimeograms reduced to the International system;
(*b*) Between Williams's *Pv* magnitudes and the revised Harvard magnitudes on the International system.

W.'s *Pv*	No. of Stars	Williams − Harvard (*a*)	(*b*)	W.'s *CI*	No. of Stars	Williams − Harvard (*a*)	(*b*)
m m		m	m	m m		m	m
2·99	21	−0·05	0·00	−0·35	25	−0·04	−0·01
3·00 to 3·99	22	− ·05	− ·01	−0·34 to − ·30	48	− ·04	− ·02
4·00 ,, 4·49	20	− ·02	− ·01	− ·29 ,, − ·25	53	− ·02	·00
4·50 ,, 4·99	32	− ·02	− ·01	− ·24 ,, − ·20	25	− ·03	− ·02
5·00 ,, 5·49	43	− ·03	− ·01	− ·19 ,, 0·00	19	·00	·00
5·50	42	−0·04	−0·03	+0·01	10	−0·06	−0·04
All	180	−0·03	−0·01	All	180	−0·03	−0·01
Probable Error of a single difference W − H			±0·08				±0·07

Summary

The paper contains the magnitudes in three colours of the O and early B stars south of −35° and brighter than 6·0 magnitude, together with those of a few stars further north, from which have been deduced *Pg* and *Pv* magnitudes and colour indices. The *Pv* magnitudes are compared with Harvard values.

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OBSCURED REGIONS IN THE GREENWICH ASTROGRAPHIC ZONE

E. G. Martin

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Volume IV of the *Greenwich Astrographic Catalogue*, 1921, gives (on pp. 177–181) counts of stars to various magnitude limits, based on photographic magnitudes derived from plates photometrically standardised on the polar sequence. Some results from these counts are given in the Introduction to the volume, but a detailed examination of the individual counts has so far not been carried out. It appears likely that such counts may give information on regions suffering obscuration and absorption in this zone, which, as it covers the celestial pole, is an important region.

The area concerned is from 63° to 117° galactic longitude and from +4° to +51° galactic latitude, but counts for the region within 3° of the celestial pole were not published. The counts, numbering 441, cover regions 40′ square, this being the most even portion of the plates, thereby omitting the more irregular edges. In the present investigation, the area was divided in galactic longitude into five strips each 10° wide centred at 70°, 80°, 90°, 100° and 110°. Mean values of log N_m for values of galactic latitude differing by about 9° were obtained from the eighty or so star counts in each longitude strip, detailed examination showing that mean values could safely be used over 10° of galactic latitude; the mean latitudes adopted for each strip differed by less than a degree. It was thus possible to collect 6, 6, 7, 7 and 4 separate mean values of log N_m in the five longitude strips for values of galactic latitude. Each mean value derived in this way thus depends on about fifteen separate regions 40′ square. As the counts were made for each half-magnitude, mean values of log N_m for each strip and for galactic latitudes spaced 9° apart were available for magnitudes $10^{m}.0$, $10^{m}.5$, $11^{m}.0$ . . . $13^{m}.0$ photographic.

It seemed desirable to make a comparison of every point in magnitude and position in this réseau with the most recent values of van Rhijn in *Gron. Pub.*, 43, Table X. Due allowance was made for the fact that van Rhijn adopted a slightly different position for the pole of the galaxy from that used at Greenwich, which was based on Lund Tables (adopted by the I.A.U.). The comparison showed that there is an average difference for the relevant magnitude range of +0·20 in log N_m in the sense Greenwich minus van Rhijn in this area of the sky. The mean differences over the whole réseau of points were examined to see whether there was any variation with galactic longitude, with galactic latitude or with magnitude. In galactic longitude no variation in the mean difference for the various strips was found. In galactic latitude there is an indication of a slight maximum at +25°, which may be due, however, to errors of observation. In magnitude no variation is discernible. Lindsay and Bok have published in *H.A.*, **105**, 1937, figures which show a disagreement between their own magnitudes and those of van Rhijn. The Harvard and Groningen values agreed closely at magnitude 12·5, but a considerable difference was found for stars of magnitude 10. The comparison, however, was mainly confined to regions in the southern hemisphere, and the effect found by them does not seem to be present in the Greenwich region.

The constant difference in log N_m between Greenwich and Groningen can be attributed to the fact that the counts in volume IV were not corrected to the International scale (see vol. IV, p. A 14). The amount of this correction was at that time unknown. The magnitudes used in the counts were based on the magnitudes of the Harvard polar sequence given in *H.C.*, 170, 1912, and the results of the counts were compared in the

Introduction to that volume with *Gron. Pub.*, 27, 1917, the latter using data for the stars fainter than $10^{m}.0$ based on counts of the selected areas. This comparison, cited as volume IV original, gives the following difference between the mean values of log N_m for the whole area and for all limiting magnitudes:—

Vol. IV original—*Gron. Pub.*, 27 = −0·02.

The corrections necessary to reduce *Gron. Pub.*, 27, to the International scale were published in *Trans. I.A.U.*, 2, 93, 1925, together with a corrected table of log N_m on p. 96. The correction is constant between $10^{m}.0$ and $13^{m}.0$ and the resulting comparison is

Gron. Pub., 27—*Gron. Pub.*, 27, corrected = +0·17;

a check comparison gives

Vol. IV original—*Gron. Pub.*, 27, corrected = +0·15.

Gron. Pub., 43, was published some twelve years later than *Gron. Pub.*, 27, and is based, for the fainter stars, on much fuller data from selected areas. Values of log N_m are given, not only for galactic latitude, but also for galactic longitude, smoothed values in galactic latitude having been analysed to deduce the variations in galactic longitude. A comparison yields

Gron. Pub., 27—*Gron. Pub.*, 43 = +0·25.

Applying the difference due to correction of *Gron. Pub.*, 27, we have

Gron. Pub., 27, corrected—*Gron. Pub.*, 43 = +0·08.

The divergence is probably mainly due to additional material. The present paper, using all the separate counts contained in volume IV, and reducing afresh in the manner described earlier, yields the following comparison taken over the réseau of points (see para. 2):—

Vol. IV present—*Gron. Pub.*, 43 = +0·20,

agreeing very closely with the comparison

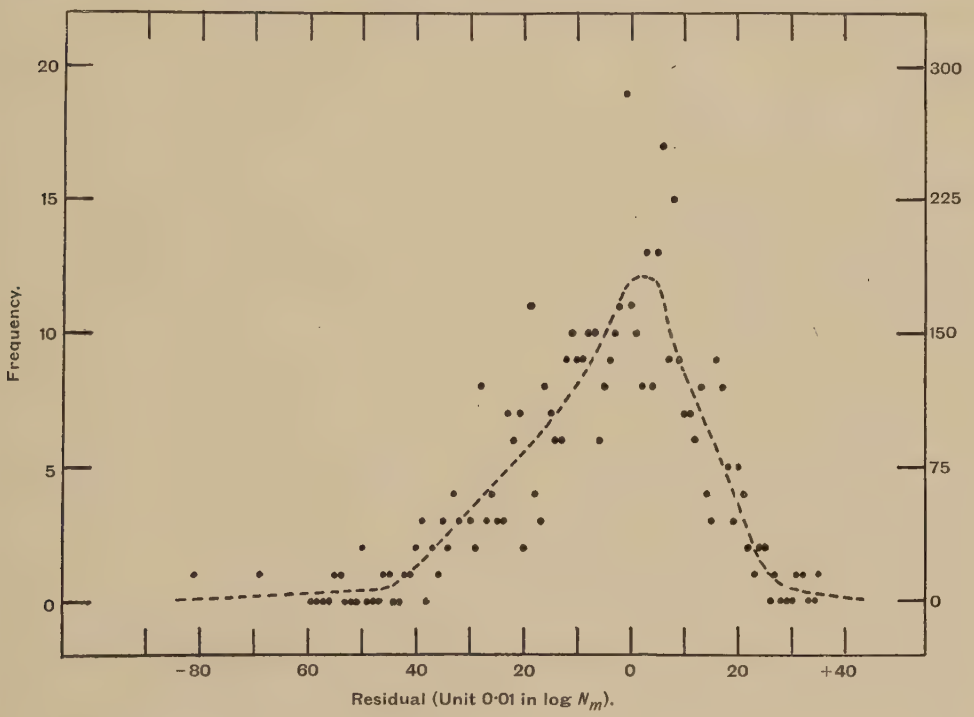
Vol. IV original—*Gron. Pub.*, 43 = +0·23.

The mean difference does not preclude an examination of the individual counts against mean values of the counts for various galactic latitudes and longitudes. For each longitude strip, the mean log N for each half-magnitude was plotted against galactic latitudes, together with the values from van Rhijn.* This plainly showed not merely that the Greenwich values were higher, but also that they ran generally parallel for galactic latitudes larger than +25°. Below this latitude the Greenwich values dropped considerably in nearly all strips. This is also to be observed in the table in volume IV, p. A 13, where the values from van Rhijn are shown to be considerably higher than Greenwich for galactic latitudes +15° and +7°. (It must, of course, be borne in mind that this table needs the correction mentioned in the previous paragraph.) It is stated on p. A 14 that "there appears to be a real difference between his results and these as regard galactic condensation." The values given by van Rhijn are smoothed values, and for the fainter stars under consideration depend on areas widely spaced so that they may entirely miss regions suffering absorption. Smoothing has also tended to eliminate variations.

During the last few years it has been generally recognised that absorption is present,

* *Gron. Pub.*, 43, Table X, 1929.

veiling the galactic equator but shading off towards the galactic poles. Variations are now also known to exist in galactic longitude, and the photographic absorption deduced by Stebbins and Huffer in various galactic longitudes shows that while absorption reaches a maximum at longitude 350° there is a secondary maximum at 90° and 110°, *i.e.* in the centre strips of the region under investigation.* The values of log N_m in *Gron. Pub.*, 43, Table X, show a secondary maximum, but it occurs some 30° earlier in galactic longitude at the galactic equator. At higher latitudes the secondary maximum is much less visible. It was therefore decided to draw a curve parallel to the van Rhijn values through the Greenwich points for latitudes 50° to 25°, so that the line through these points made the sum of the residuals equal to zero. The curve was continued parallel to the van Rhijn values from 25° to 5° galactic latitude. This gave curves of log N_m (hereinafter called standard curves) for each of the five strips and for each half-magnitude.



For each individual count a residual from these standard curves (unit 0·01 in log N_m) was derived for each half-magnitude and a straight mean taken. This mean of the seven residuals from the standard curves drawn for $10^m.0$ to $13^m.0$ gives a first indication of the divergence of any region from the average.

The figure shows the frequency distribution of residuals, the left-hand scale referring to the separate unsmoothed values, the unit being 0·01 in log N_m. The right-hand scale refers to the smoothed curve obtained by taking totals over fifteen consecutive residuals. The frequency curve shows considerable asymmetry, negative residuals being in excess. Assuming the scatter to be due to accidental error, the probable error in log N_m of a single count for regions at latitudes greater than 25° is ± ·102; for those less than latitude 25° it is ± ·122. There are five regions with positive residuals slightly more than three times the p.e., but there are twenty-nine regions with negative residuals larger than three times, the largest residual being eight times. These twenty-nine regions have therefore

* *Gron. Pub.*, 47, p. 23, 1936.

been deemed to be outstanding regions from the average and are spaced in latitude as follows:—

+ 4°	to +10°	9	19
10°	,, 20°	7	
20°	,, 30°	5	10
30°	,, 40°	4	
40°	,, 50°	4	

It will be seen that two-thirds of the outstanding regions are in the lower latitudes as compared with one-third in the higher. This confirms the generally accepted hypothesis of an absorption increasing towards the galactic equator. There is also a tendency for the central strips to contain more outstanding regions than the outer strips. This indicates higher absorption around longitude 90°–100° and would confirm the secondary maximum.

The average residual for each separate area, 40′ square, was derived from the separate residuals for each half-magnitude from $10^{m}\cdot0$ to $13^{m}\cdot0$. The size of the average residual reveals the deviation from the mean log N. Small residuals are probably accidental; large residuals are more likely to be real. The slope of the seven residuals for each individual count gives an indication of variation with magnitude between the observed and mean values of log N. If the line which represents these residuals is parallel to that which represents the true log N, then the absorption is constant for the range of magnitude considered; if the line is nearer for the brighter magnitude, the absorption is greater for the fainter stars. If the line is nearer for the fainter magnitudes it would suggest that the brighter magnitudes suffer absorption which is not continued to the fainter magnitudes. This would be difficult to understand, for if the brighter stars are obscured. the fainter stars should also suffer. An examination of the slope of the individual residuals (seven for each count) reveals that 84 per cent. show parallelism, *i.e.* no absorption or a constant absorption for all magnitudes under consideration, 12 per cent. show increasing absorption, while 4 per cent. show decreasing absorption. This latter figure is probably mainly accidental. The percentages are approximately the same for regions in latitudes above and below +25°. This does not contradict the statement that the lower latitudes contain more regions suffering from absorption than the higher latitudes. Examination of the residuals which are represented by a line parallel to the true log N shows that in the higher latitudes many of them indicate no absorption while a few indicate a large absorption, but in the lower latitudes a considerably less number indicate no absorption and the number indicating large absorption has therefore gone up. It has already been stated, however, that only twenty-nine regions have been assumed to be outstanding regions, *i.e.* regions suffering heavy absorption, this being 7 per cent. of the whole number under examination. Two-fifths of these outstanding regions indicate increasing absorption, three-fifths show constant absorption, leaving none with apparent decreasing absorption, this last fact confirming the accidental origin of the 4 per cent. mentioned earlier.

The question of how much the absorption for each individual count amounts to in magnitudes, and at what distance the absorption is effective, is much more difficult to determine. The figures available in volume IV cover only the range of magnitude from $7^{m}\cdot0$ to $13^{m}\cdot0$, but from $7^{m}\cdot0$ to $10^{m}\cdot0$, owing to the paucity of stars, no detailed counts, but merely results in summarised form, are given. Actual counts are available only from $10^{m}\cdot0$ to $13^{m}\cdot0$. To obtain a complete analysis it would therefore be necessary to extrapolate the numbers for the brighter stars, which would not introduce a great error, but it would also be necessary to extend the extrapolation to the fainter stars where the error brought in would be serious. Owing to the spread in the absolute magnitudes it is not possible to make a satisfactory analysis unless the numbers of stars

are known to some three magnitudes fainter than the limit to which it is proposed to examine. An attempt was made to analyse the mean result of the counts for latitude $+7°$ using the numerical method of Seares.* The result showed that the density near the Sun was similar to that given by van Rhijn up to 1000 parsecs, but at 10,000 parsecs the density rapidly increased to a much larger value than that of van Rhijn. This increase for faint stars is noted also in volume IV, p. A 14. The work involved in the density analysis for each of the outstanding regions would, however, be so great, and the extrapolation of the counts would introduce such large uncertainties, that it is not possible to deduce the amount or distance of the absorptions.

It would of course be possible to graph the mean log N_m for a number of regions free from absorption and to plot the values for each half-magnitude, together with the value for the nearest outstanding region. This would give a Wolf diagram. It has, however, been pointed out by Bok† that this form of diagram does not permit of accurate deduction of the amount and distance of the absorption by visual inspection. The large spread in the luminosity function blurs the plotted curves, and it is only by the use of a numerical method that reliable results can be obtained, but this demands data extending to stars fainter by some magnitudes than that to which a result is desired.

We are, however, now in a position to say definitely that the twenty-nine outstanding regions in the part of the sky considered must be regarded as regions of unusual absorption and therefore accorded special treatment. A list of these regions has been made and is available for reference. The region remarked upon for its paucity of stars in volume IV, p. A 12, is found to be included in the list. Several regions are close to stars known to be reddened. Reference ‡ gives a list of known absorbing clouds to which these regions might be added.

Summary

The paper examines separate counts for the Greenwich region (Dec. $+64°$ to $87°$, galactic latitude $+4°$ to $+51°$), originally published in volume IV of the *Astrographic Catalogue*. A comparison of the average log N_m at different latitudes and longitudes with more recent figures by van Rhijn is made. A residual for each region is derived, and twenty-nine regions are adjudged to have negative values too large to be accidental but to be due to real absorption. No solution of the amount or distance of the absorption is deemed possible owing to the short magnitude interval of the counts.

* *Ap. J.*, **74**, 268, 1931.
† Bok, *Distribution of the Stars in Space*, p. 46, 1937.
‡ Hunter and Martin, *M.N.*, **100**, 685, 1940.

THE MAGNITUDE–DIAMETER LAW IN THE PHOTOGRAPHIC PHOTOMETRY OF BRIGHT STARS

D. L. Edwards

(Received 1942 August 29)

Many investigations of the relation between star magnitudes and image diameters on a photographic plate have been made. Useful summaries of such work, with the various formulæ proposed, have been given by Eberhard * and Lundmark.† All these formulæ are empirical, and fail in practical application to cases outside the range of conditions investigated. In particular they are not applicable to bright stars giving diameters larger than a certain limiting value (which varies with the different formulæ) and secondly they take no account of the effect of star colours. The first difficulty may in some cases be overcome by adjusting the exposure to give image diameters within the required range, but this is not always possible. A short exposure might cause the loss of too many fainter stars on the plate, while if an additional standardising exposure (*e.g.* the polar sequence) were given, the two exposures might have to be different, with resulting errors due to the imperfectly known relation between exposure time and diameter.

The importance of these two difficulties became apparent in an investigation of magnitude variations of γ Cas (described in another paper). This star was the brightest in the measurable field and extrapolation was necessary in deducing its magnitude from known field stars. Also, when the polar sequence was used for standardising, the only bright star available was *Polaris*, resulting in some uncertainty in this region of the scale line, in addition to the fact that its diameter (with equal exposure) was always less than that of γ Cas, so that extrapolation was again necessary. Finally, γ Cas is a blue star and the available reference stars, both in the Cassiopeia and polar regions, were of much later types. It was found that the use of any of the previously suggested formulæ resulted in very considerable errors in the deduced magnitudes of γ Cas, and it was evidently necessary to investigate the magnitude–diameter law to cover this and other similar cases. The present paper gives the results of this investigation.

Three different Zeiss triplet lenses were used: (*a*) aperture 14 cm., f.l. 70 cm., (*b*) aperture 10·4 cm., f.l. 50 cm., and (*c*) similar to (*b*) but stopped down to 2 cm. aperture. Two different types of plate were used, viz. Barnet Super Press (blue sensitive emulsion) and Ilford Hypersensitive Panchromatic, the second of which has been shown by Alter ‡ to give a very good scale of photovisual magnitudes without a filter. Photographs taken with the various lens–emulsion combinations in three regions of the Milky Way were chosen on account of the large number of measurable stars and good range of spectral types available. Full exposures gave images of bright stars which would normally be regarded as over-exposed. Images ranged from about 60 to 400 μ in diameter, covering a range of about 10 magnitudes. Diameters of all suitable stars of known magnitude (photographic or visual) were measured on each plate and the results analysed in the following manner.

In the first place only the panchromatic plates were considered, and measured diameters plotted against H.D. visual magnitudes, only stars of type Ao being used in order to determine the form of the relation for one colour only. The plotted points lay on a smooth curve with a slope rapidly increasing for large diameters; and after trying various types of formulæ the following was adopted as giving the best fit:—

$$m = a - b(D - kD^2), \qquad (1)$$

* *Hdb. d. Ap.*, II, 2, 432, 1931. † *Ibid.*, V, 1, 296, 1932. ‡ *M.N.*, 100, 387, 1940.

where m = magnitude, D = diameter and a, b, k are constants. Thus if $D - kD^2$ is taken as the variable instead of D a linear relation is given with m. The formula could be written

$$m = a - bD - cD^2 \qquad (2)$$

when it appears as an extension of Scheiner's simple law ($m = a - bD$) by the addition of a D^2 term. The reason for putting it in the form (1) will appear later. The constant k, being multiplied by D^2, must be determined to 5 places of decimals; its computed value was 0·00140 (with D measured in microns), and was found to be practically the same for all the plates taken with different lenses. The above value is the mean from all the plates.

It is evident that even this formula must be of limited application, since the function $D - kD^2$ has a maximum, and decreases again rapidly for very large values of D. For the given value of k this maximum is at about 360 μ, but the formula is reasonably accurate up to about 340 μ, which is sufficient for most practical purposes as it is rarely necessary to exceed this diameter, and in any case such large images are very difficult to measure accurately. It was found that the addition of $+10^{\cdot 018(D-340)}$ to the term in brackets in equation (1) gave good results for all diameters up to about 500 μ within the limits of measurement errors. This empirical type of correction to large diameters was preferable to adding terms in D^3 or higher powers in equation (1), since in the latter it was difficult to determine constants in such a way as to improve the brighter magnitudes without affecting the fainter ones. Also, such a formula would be cumbersome in use for all values of D, whereas the term suggested above is obviously negligible when $D < 340$ μ.

The next step was to treat stars of other spectral types in the same way. It was found that they gave a family of curves similar to that of the Ao stars. All the curves converged almost to coincidence for small values of D (below 200 μ) but separated considerably for larger values, the redder stars giving the smaller slopes. For diameters above 300 μ, stars differing by as much as one magnitude in brightness, if of different colours, might give equal diameters. All these curves could be expressed by equation (1), with the same constants a and b (for stars on the same plate) if k was given an appropriate value according to the colour. The advantage of this equation over the form (2) (in addition to its greater practical convenience) thus lies in the fact that k is a parameter dependent on colour alone, while a and b are constants of the whole plate, independent of star colours. The constant b is, of course, the slope of the linear relation mentioned above and is related to Ross's "astrogamma."

Values of k determined for 4 different types of stars and plotted against the mean colour indices (taken from King's * values) gave a relation from which the best value of k for any star of known colour could be interpolated. It was found that good values of k are given by

$$k = 10^{-5}(140 - 13C), \qquad (3)$$

where C is the colour index. Equations (1) and (3) together give the final form of the adopted magnitude–diameter law, with the addition (if necessary) of the term $10^{p(D-340)}$ where p also varies slightly with colour but may be assumed, without serious error, to have the mean value of 0·018.

In dealing with stars of unknown colour it is sufficient to assume first an approximate value (and hence an approximate k) from its spectrum (if known); otherwise to assume $k = 0{\cdot}0014$ as for an A-type star. If this value of k is used in computing m_{pv} and m_p the results will both be affected in the same sense by the error in k, and the error in the resulting C.I. will only be of a second order. This measured C.I. may be used to give a better value of k for final determinations of magnitudes.

Fig. 1 shows the results from a typical plate, and illustrates the remarks made above.

* *Hdb. d. Ap.*, V, 1, 173, Table 9 *c*, 1932.

In (*a*) measured diameters of all stars are plotted against magnitudes, the different spectral types being distinguished by different symbols. In (*b*) the "reduced" diameters ($D - kD^2$) of the same stars are plotted, and the reduction to a linear relation is evident, as well as the elimination of the scatter due to colour which is so pronounced in (*a*).

Measures made on Barnet Super Press plates were treated in the same way as above, except that photographic instead of visual magnitudes were used. Unfortunately good measures of m_p for bright stars are scarce (possibly owing to the difficulties dealt with in the present paper), but the lists of Bergstrand *, Yerkes † and Balanowskaja ‡ gave

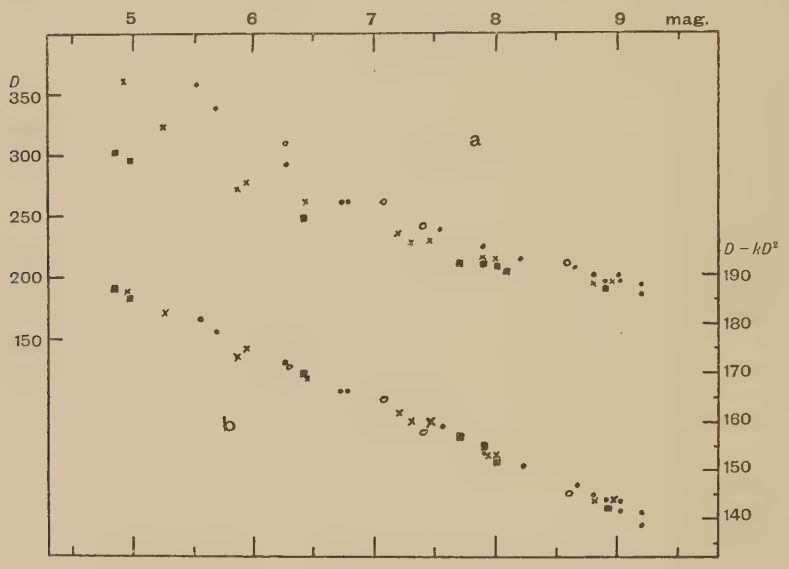


FIG. 1.—*Magnitude–Diameter Law.*

Open Circles	=	Spectral Type	B
Filled ,,	=	,,	A
Crosses	=	,,	F
Squares	=	,,	K

sufficient material for the purpose in the three Cassiopeia regions covered by the plates. Values from the two last lists were reduced to Bergstrand's scale by the formulæ given by the latter and the mean values taken. Any zero point error, if present, was immaterial for the present purpose, as it would merely imply a general shift of the relation as a whole (*i.e.* of the constant *a*). As an additional check, values obtained by adding the C.I. (based on spectral type) to visual magnitudes were also used, but were treated quite independently. They naturally gave more scatter, but the mean results were in close accord with those from observed values.

The rather unexpected result was found that not only did the same relation (1) hold as for the photovisual plates, but the same values of k (equation (3)) were also applicable, in spite of the different magnitude scales and of the very different types of emulsion used. This rather suggests that the actual values of k must depend, at least partially, on the quality of the lens (possibly the lack of achromatism). The fact that the three lenses used were of the same type (Zeiss triplets) might account for the same values of k being found. Other types, such as doublets or anastigmats, might give different values, but the actual necessity for the parameter k and its variation with C.I. has presumably a photographic origin.

The only alternative to a formula such as that suggested would be to plot measured

* *Ups. Med.*, No. 57, 1933. † *Ap. J.*, 73, 125, 1931. ‡ *Pulk. Bull.*, 13, No. 2, 1932.

diameters against magnitudes for known stars on a plate, draw the best curve possible through the points thus obtained, and determine unknown magnitudes graphically from this curve without assuming any analytical relation. This method has been used at some observatories, but is open to objection for bright stars. The colour effect would make the drawing of such a curve difficult unless the stars used happened to have a small range in spectral type, and in any case the deduced magnitudes of unknown stars might be seriously in error if their spectral types differed much from the mean of the standard stars. Also, if the unknown star were brighter than any of the standards additional error would be caused by the necessity for extrapolation, which is very difficult to apply graphically to curves of this shape.

The advantage of the formula over earlier ones (in addition to its allowance for colour effect) is in the greater range of application to bright stars. Amongst earlier formulæ those of Turner and Charlier (using $\sqrt{D}$ and $\log D$ respectively in a linear relation with m) gave the best fits with the present observations, but both failed at diameters above about 250 μ. The present formula should cover a range of at least 9 magnitudes for all spectral types.

The formula is of course purely empirical, and not based on any photographic theory. It is of interest, however, to note the implications involved in the theory of image formation in the emulsion. As shown by Ross *, Bouguer's law gives the intensity i at a point distant x from the boundary of the central core of uniform illumination I in an image as

$$i = Ie^{-\kappa x},$$

where κ is a constant depending on turbidity and other factors. If the point x is chosen at the apparent edge of the image, where the measurements are made, then i will be constant for all images and

$$x = c + (\log I)/\kappa,$$

so that

$$D = g + 2x = c' + (\log I).2/\kappa,$$

where g is the diameter of the core, c and c' are constants. This is equivalent to the simple Scheiner law relating magnitude and diameter. If, instead of Bouguer's law, we assume

$$i = Ie^{-\kappa(x+\mu x^2)} \qquad (4)$$

then similar substitutions will lead to an equation which is equivalent to equation (1). The light distribution forming a stellar image in a photographic emulsion as given by a law of type (4) is therefore implied by the magnitude–diameter law suggested in the present paper. In formula (4) both κ and μ must vary with colour.

Summary

A redetermination has been made of the relation between photographic image diameters and magnitudes of stars obtained with different lenses and emulsions. Earlier formulæ fail when applied to bright stars, and take no account of the effect of star colours (here shown to be present, and to be important for large diameters). A new formula is suggested, of extended applicability and including a parameter dependent on colour. The implications of this formula on Bouguer's law of light distribution in the photographic emulsion are described.

Norman Lockyer Observatory,
Sidmouth:
1942 *August* 27.

* *The Physics of the Developed Photographic Image*, Kodak Ltd., 1924.

MAGNITUDES AND COLOUR INDICES OF γ CASSIOPEIÆ

D. L. Edwards

(Received 1942 August 29)

In 1940 June a series of photographs of γ Cas was started, with the object of determining its magnitudes (photovisual and photographic) from measurements of image diameters. Photographs were taken every week when possible at the beginning, but at longer intervals later when the magnitude variations were smaller. The instrument used was a Zeiss triplet lens of f.l., 50 cm. stopped down to about 2 cm. aperture. This was attached to the "Kensington" equatorial of the Norman Lockyer Observatory. Two different kinds of plates were used: Barnet Super Press, for photographic magnitudes, and Ilford Hypersensitive Panchromatic for photovisual. No filter was used with the latter, as Alter * has found that a very good photovisual scale is obtained in this way. Exposures of 5 minutes were given in every case, the resulting image diameters of γ Cas ranging from about 240 to 360 μ. Good definition was obtained over a field of about 6° diameter. Diameters of suitable Cassiopeia stars were used in computing the diameter–magnitude scale line by means of the formulæ suggested in a previous paper.

For the photovisual scale H.D. visual magnitudes of these stars were used, and for three plates (taken on different dates) an additional exposure on the polar sequence was used as a check. The latter gave both independent determinations of the γ Cas magnitudes and a check on the accuracy of the use of Cassiopeia standards. No appreciable difference was found between results from the two methods, so that reliance may be placed on the remaining plates where only Cassiopeia standards were used. Small errors were found, depending on the position of the image on the plate. These were carefully determined and found to be related to the distance of the image from a straight line which appeared to be the axis of a slight tilt of the plate with respect to the optical axis. This was confirmed by taking two plates, with the telescope reversed between the exposures, thus changing the position of each image with regard to the line. The errors were all changed, but found to bear the same relation to distance from the line as before; they amounted to $\pm$ $0^m.11$ per degree distance. After applying suitable corrections there was only small remaining scatter of the measured points round the scale line. The probable error in magnitude for one star was $\pm$ 0·05 (average for all plates).

For the photographic scale on B.S.P. plates, magnitudes of the Cassiopeia stars were first determined directly, with the help of the N.P.S., on plates taken specially for this purpose. These stars were used as standards for all the other plates in measuring γ Cas. This was done partly to avoid the necessity for two exposures on every plate, and partly on account of the fact that there are very few polar stars within the magnitude range required. Even *Polaris* itself was fainter than γ Cas on all except one of the dates of observation. Other determinations of m_p for the brighter Cassiopeia stars were too scarce to give a suitable scale line, but four values from Pulkovo † were available as a check. The probable error of one determination of m_p was about $\pm$ 0·06, so that the p.e. of the colour index is about $\pm$ 0·08. The final results are given in the table.

Magnitude variations were more pronounced in 1940, tending to become steadier by the end of the year and in 1941, with a general slight increase in brightness

* *M.N.*, 100, 387, 1940.

† *Pulk. Bull.*, 13, No. 2, 1932.

followed by a decrease. The more prominent fluctuations were accompanied by considerable changes in the spectrum. At, and just preceding, the minima of 1940 June 29 and September 21 the *H* lines showed well separated double emission components with strong central absorption and rather faint "dish-shaped" absorption fringes. *He*I absorption lines at 4471, 4026, 3964, were strong and sharp, and *O*II absorption rather faint. During the rise to maxima at August 24 and October 7 the *H* central absorption became fainter and the dish-shaped absorption stronger, the *He*I lines mentioned became fainter and more diffuse, *O*II a little stronger, and λ 3888 (*He*I) very strong. The same changes were also quite pronounced during the small dip in magnitude between August 2 and August 24. From November 22 onwards (the more quiescent period) the central *H* absorptions disappeared, diffuse absorption became strong, and λ 3888 very faint or absent. Many other changes were noted, but a more detailed description is reserved for a later paper; the above remarks are given as support for the reality of the observed magnitude changes.

The colour index changes are subject to greater uncertainty and do not show such pronounced correlation with spectrum changes. The mean C.I. over the whole period is −0·12, which corresponds to the average C.I. of B6 stars. As γ Cas is a B2 star (average C.I. −0·30) this indicates considerable reddening, which is probably mainly intrinsic.

Magnitudes and Colour Indices of γ Cas

J.D. 2429782–2430443

Date	m_{pv}	m_p	C.I.	Date	m_{pv}	m_p	C.I.
1940 June 1	2·37	2·06	−·31	1940 Dec. 21	2·33	2·15	−·18
,, 5	2·66	2·36	−·30	1941 Jan. 1	...	2·18	...
,, 7	2·50	2·40	−·10	Feb. 1	2·33	...	...
,, 29	2·76	2·64	−·12	,, 21	2·40	2·13	−·27
Aug. 2	2·42	2·15	−·27	May 16	2·10	1·95	−·15
,, 11	2·45	2·30	−·15	June 12	2·30	2·09	−·21
,, 24	2·20	2·06	−·14	Aug. 18	2·29	2·18	−·11
Sept. 6	...	2·32	...	,, 26	2·49	2·41	−·08
,, 21	2·53	2·53	·00	Sept. 16	2·23	2·22	−·01
,, 23	2·34	2·30	−·04	Oct. 11	2·50	...	...
,, 23	2·47	2·38	−·09	Nov. 21	2·16	2·16	·00
Oct. 7	2·05	2·06	+·01	1942 Jan. 7	2·30	2·14	−·16
,, 21	2·28	2·10	−·18	,, 7	...	2·05	...
Nov. 22	2·20	2·17	−·03	Mar. 23	2·55	...	...
Dec. 19	2·20	2·20	·00	,, 24	2·55	...	...
,, 19	2·20	2·25	+·05				

Summary

Magnitude observations (photographic and photovisual) have been made of γ Cas by diameters of images taken on Barnet Super Press and Ilford Hypersensitive Panchromatic plates, using a new magnitude–diameter law.

Results are tabulated for the period 1940 June to 1942 March 24, the variations discussed and correlations with spectrum changes indicated.

The average colour index obtained suggests pronounced reddening.

Norman Lockyer Observatory,
Sidmouth:
1942 *August* 27.

STELLAR PARALLAXES DETERMINED PHOTOGRAPHICALLY AT THE ROYAL OBSERVATORY, CAPE OF GOOD HOPE (THIRTEENTH LIST)

(Communicated by H.M. Astronomer)

(Received 1942 July 20)

The form of publication is similar to that of previous lists. Nearly all the stars were observed on account of large proper motion, and the proper motion in R.A. has generally been fairly well confirmed. The sign of the proper motion given in U.O.C. 48 for star No. 1196 has been altered to conform with our determination. The proper motions given in the first line for each star have been taken from miscellaneous sources, not always those corresponding to the name of the star.

For two stars, one of which is *Proxima Centauri*, a second determination of the parallax has been made and the result from the combined series of plates is given.

No.	Name and D.M. No.	Mag. Vis. Phot.	Type	R.A., Dec. (1900·0)	Unit 0″·001 Proper Motion R.A.	Proper Motion Dec.	P.E. Wt. 1	Parallax	P.E.
				h m s					
1101	G.C. 378	6·50	Go	0 13 33	+ 408	− 134	±34	+ 23	±11
	−8° 38	7·06		−8° 36′·3	+ 434				± 5
1102	F.S. 86	...	Mo	0 16 23	+ 64	− 822	±35	+ 64	± 9
	−46° 76	11·7		−46° 16′·8	+ 59				± 6
1103	F.S. 294	...	...	0 59 10	+ 170	+ 99	±32	+ 14	± 9
	C.A.Z. −49° 199	12·7		−48° 0′·9	+ 203				± 7
1104	F.S. 20556	...	...	0 59 11	− 238	−1693	±20	+ 22	± 6
	C.A.Z. −47° 148	13·1		−46° 17′·0	− 297				± 5
1105	ν Phœnicis	4·88	Go	1 10 40	+ 662	+ 187	±30	+ 48	± 9
	P.G.C. 288	6·2		−46° 03′·9	+ 666				± 7
1106	21 Eridani	6·00	G5	3 34 05	− 15	− 204	±30	+ 15	± 9
	P.G.C. 831	6·78		−5° 56′·8	− 25				± 6
1107	G.C. 4399	7·07	G5	3 35 43	+ 380	− 209	±30	+ 6	± 9
	−2° 690	7·85		−2° 39′·0	+ 369				± 7
1108	F.S. 1254	...	Mo	4 13 36	+ 231	+ 76	±33	+ 7	±10
	C.A.Z. −41° 66	11·6		−41° 02′·8	+ 170				± 8
1109	F.S. 1332	...	...	4 26 54	+ 246	− 294	±32	+ 23	± 9
	C.A.Z. −49° 108	11·6		−48° 44′·9	+ 220				± 7
1110	G.C. 5786	6·81	F5	4 41 04	− 2	+ 265	±29	− 20	± 9
	−48° 1479	7·6		−48° 31′·2	− 3				± 8
147	G.C. 5824	7·77	G5	4 43 07	− 458	− 357	±24	+ 56	± 5
	−50° 1492	8·0		−50° 14′·7	− 468				± 1
1111	Z.C. 2676	8·4	G5	5 02 59	− 52	+ 133	±33	+ 9	± 9
	−51° 1367	9·5		−51° 34′·3	− 47				± 7

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				h m s					
1112	ζ Pictoris	5·52	F8	5 16 55	+ 6	+ 216	±36	+ 18	±11
	P.G.C. 1287	6·6		−50° 42′·8	+ 6				± 8
1113	G.C. 6639	8·3	G5	5 19 47	− 44	+ 195	±28	+ 23	± 9
	−42° 1912	9·4		−42° 25′·2	− 57				± 6
1114	F.S. 1730	...	K7	5 20 42	+ 153	+ 131	±34	+ 1	±11
	−46° 1819	11·1		−46° 32·9	+ 140				± 8
1115	Z.C. 3065	8·5	Ko	5 40 46	+ 41	+ 221	±33	+ 13	± 9
	−47° 1997	9·6		−47° 52′·3	+ 46				± 7
1116	Z.C. 3147	8·9	G5	5 47 27	+ 37	+ 213	±33	+ 13	±10
	−43° 2082	8·7		−43° 43′·9	+ 37				± 7
1117	P.G.C. 1521	6·22	F8	6 01 36	− 85	+ 229	±37	+ 45	±12
	−45° 2300	7·0		−45° 02′·2	− 84				± 9
1118	P.G.C. 1524	5·82	F5	6 01 48	− 76	+ 244	±36	+ 19	±13
	−45° 2302	7·0		−45° 04′·7	− 69				±10
1119	F.S. 2066	...	...	6 07 27	+ 85	+ 241	±23	− 6	± 7
	C.A.Z. −43° 152	12·0		−42° 40′·8	+ 82				± 5
1120	F.S. 2283	...	...	6 28 52	− 278	− 18	±27	+ 56	± 9
	−43° 2523	11·3		−43° 27′·6	− 275				± 5
1121	Z.C. 4008	6·13	Ko	6 51 34	− 62	+ 220	±29	− 7	± 8
	−50° 2458	7·3		−50° 29′·4	− 68				± 5
1122	Z.C. 4097	8·0	Ko	6 57 16	+ 21	+ 214	±35	+ 26	±10
	−41° 2725	9·1		−41° 14′·7	+ 40				± 8
1123	Z.C. 4147	9·2	K2	7 00 46	− 108	+ 401	±36	+ 52	±10
	−43° 2904	9·4		−43° 25′·4	− 84				± 8
1124	F.S. 2865	...	...	7 08 32	+ 220	− 15	±27	+ 17	± 7
	−45° 2997	11·1		−46° 01′·8	+ 206				± 6
1125	Ci. 20, 440	...	...	7 42 24	+ 170	− 460	±28	+ 38	± 8
	Ross 391	13		−13° 41′·2	+ 119				± 6
1126	F.S. 4054	...	...	8 13 12	− 200	+ 134	±31	+ 22	± 9
	−41° 3948	12·6		−41°54′·1	− 216				± 6
1127	F.S. 4586	...	G5	8 33 23	− 53	− 226	±28	+ 26	± 8
	−49° 3675	10·2		−49° 44′·7	− 50				± 7
1128	F.S. 5128	...	Mo	8 50 04	+ 9	− 51	±31	+ 6	±11
	−40° 4707	10·8		−41° 04′·8	+ 27				± 7
1129	23 Hydræ	5·40	Ko	9 11 44	+ 4	0	±19	+ 29	± 6
	P.G.C. 2490	6·40		−5° 56′·2	+ 10				± 3
1130	F.S. 5846	9·8	Ko	9 13 25	− 205	+ 113	±31	+ 24	± 8
	−48° 4571	10·9		−48° 53′·1	− 212				± 6
1131	G.C. 13312	7·2	Go	9 33 55	− 48	+ 227	±23	+ 17	± 6
	−49° 4546	8·0		−49° 32′·8	− 38				± 5

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				h m s					
1132	F.S. 6541	...	...	9 34 54	+ 131	− 83	±24	+ 9	± 7
	−42° 5564	11·0		−42° 11′·1	+ 124				± 5
1133	F.S. 6642	...	...	9 43 15	− 224	+ 60	±26	+ 17	± 8
	−49° 4678	11·3		−49° 55′·6	− 209				± 6
1134	F.S. 6744	...	...	9 47 04	− 154	+ 84	±22	+ 17	± 7
	C.A.Z. −43° 816	11·9		−42° 23′·9	− 157				± 5
1135	F.S. 7695	...	Ko	10 17 36	+ 221	− 181	±26	− 4	± 8
	−43° 6190	10·7		−44° 00′·2	+ 267				± 5
1136	F.S. 7784	...	...	10 21 13	− 157	+ 75	±26	+ 40	± 7
	−44° 6469	12·2		−44° 22′·9	− 135				± 6
1137	F.S. 8403	...	Ko	10 49 04	− 159	+ 95	±26	+ 10	± 8
	−44° 6890	11·1		−44° 26′·9	− 140				± 6
1138	F.S. 8613	...	G	11 02 22	− 241	− 59	±28	− 9	± 8
	−45° 6692	11·7		−45° 37′·7	− 243				± 6
1139	δ Crateris	3·82	Ko	11 14 20	− 125	+ 199	±32	+ 12	±10
	P.G.C. 2989	4·82		−14° 14′·2	− 170				± 6
1140	F.S. 9170	...	...	11 32 55	− 526	− 154	±27	+ 38	± 7
	−47° 7000	12·3		−48° 03′·9	− 535				± 5
1141	F.S. 9501	...	...	11 53 12	− 230	− 8	±36	+ 12	±10
	C.A.Z. −43° 77	13·7		−42° 26′·1	− 214				± 8
1142	G.C. 16446	9·6	G5	11 57 08	− 203	− 21	±27	+ 2	± 7
	−48° 7070	9·8		−48° 10′·0	− 213				± 6
1143	G.C. 16765	6·78	F8	12 12 17	− 271	− 43	±24	+ 36	± 7
	−48° 7307	7·9		−48° 22′·1	− 242				± 6
1144	Ci. 20, 703	...	...	12 19 33	+1200	−2180	±23	+101	± 7
	Ross 695	12·4		−17° 37′·5	+1136				± 5
1145	Ci. 20, 722	...	...	12 30 43	− 840	− 10	±22	+ 52	± 7
		12		−76° 24′·0	− 897				± 4
1146	F.S. 10467	...	Ko	12 50 29	− 221	− 72	±19	+ 11	± 6
	−46° 8264	12·2		−46° 34′·0	− 232				± 5
1147	Ci. 20, 753	9·5	K2	12 55 14	− 730	0	±30	+ 73	± 7
	−1° 2754	10·6		−2° 09′·9	− 799				± 6
1148	F.S. 10842	...	...	13 10 34	− 239	+ 22	±32	+ 32	± 9
	C.A.Z. −47° 441	13·2		−46° 38′·7	− 220				± 8
1149	F.S. 11134	...	...	13 27 16	− 542	+ 94	±23	− 9	± 6
	C.A.Z. −43° 432	13·2		−42° 10′·6	− 500				± 5
1150	Ci. 20, 794	9·3	K5	13 34 59	− 370	+ 480	±25	+ 44	± 7
	−3° 3508	10·5		−3° 41′·5	− 343				± 5
1151	Ci. 20, 810	...	...	13 42 00	− 440	− 60	±36	− 10	±10
	−71° 1520	11·2		−71° 29′·6	− 421				±10

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				h m s					
1152	G.C. 18966	6·32	F5	13 57 13	+ 19	+ 76	±38	+ 12	±10
	−31° 10859	7·7		−31° 12′·3	+ 20				± 9
1153	G.C. 19107	8·5	Go	14 04 00	+ 30	− 315	±27	+ 14	± 7
	−44° 9127	9·0		−44° 30′·5	+ 44				± 6
1154	F.S. 11862	...	Go	14 04 04	+ 43	− 322	±33	+ 21	± 9
	−44° 9130	10·8		−44° 29′·9	+ 76				± 7
1155	Ci. 20, 852	9·2	Ko	14 15 18	− 510	− 110	±34	+ 54	± 9
	−39° 8857	10·0		−39° 55′·0	− 565				± 7
1156	Z.C. 12311	7·5	G5	14 20 49	− 305	+ 44	±34	+ 54	± 8
	−51° 8206	8·8		−51° 29′·0	− 304				± 5
551	*Prox. Cent.*	...	...	14 22 57	−3653	+ 842	±33	+763	± 7
		12		−62° 15′·3	−3783				± 2
1157	Ci. 20, 864	9·3	K5	14 25 37	−1250	− 180	±32	+ 51	± 8
	−7° 3856	10·5		−8° 11′·8	−1270				± 6
1158	G.C. 20118	6·48	Ko	15 51 17	− 29	− 328	±30	+ 47	± 7
	−48° 9494	7·7		−48° 27′·1	+ 4				± 6
1159	F.S. 12701	...	Ko	14 57 45	− 295	− 87	±33	+ 9	± 8
	−49° 9297	11·7		−49° 32′·3	− 307				± 7
1160	P.G.C. 3899	5·06	F8	15 15 10	− 140	− 143	±27	+ 29	± 6
	−47° 9922	6·2		−47° 33′·8	− 125				± 4
1161	F.S. 13290	...	Ko	15 24 56	− 61	− 210	±26	− 1	± 6
	−49° 9705	11·5		−49° 33′·1	− 49				± 6
1162	Z.C. 14072	...	Go	15 43 50	− 132	− 150	±29	+ 28	± 8
	−49° 10056	10·2		−49° 37′·1	− 134				± 7
1163	ζ Scorpii	3·75	K5	16 47 33	− 127	− 214	±26	+ 26	± 6
	P.G.C. 4292	5·6		−42° 11′·4	− 136				± 5
1164	F.S. 15850	...	G5	16 52 44	− 135	− 162	±23	+ 24	± 5
	−51° 10635	10·7		−51° 05′·9	− 140				± 4
1165	G.C. 23376	7·2	Go	17 12 16	− 42	− 217	±31	+ 12	± 7
	−48° 11605	7·1		−48° 26′·3	− 11				± 6
1166	F.S. 16703	...	Mo	17 22 20	− 261	− 182	±28	+ 60	± 7
	−51° 10924	11·1		−51° 33′·0	− 245				± 6
1167	Ci. 20, 1044	...	...	17 28 38	− 430	− 307	±27	+ 21	± 7
	−35° 11724	10·5		−35° 53′·7	− 334				± 6
1168	μ Aræ	5·26	G5	17 36 12	− 14	− 201	±28	+ 94	± 7
	P.G.C. 4478	7·2		−51° 46′·8	− 6				± 5
1169	F.S. 17678	...	Go	17 56 16	+ 49	− 241	±26	+ 6	± 7
	−45° 12143	10·4		−45° 51′·3	+ 60				± 5
1170	F.S. 17912	...	K	18 09 41	− 70	− 222	±19	+ 10	± 5
	−49° 12033	12·8		−49° 31′·1	− 82				± 5

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				h m s					
1171	Z.C. 17325	8·4	G5	18 16 29	+ 43	− 159	±26	+ 18	± 7
	−45° 12446	9·7		−45 11′·1	+ 20				± 6
1172	F.S. 18041	...	F8	18 17 39	− 11	− 214	±32	− 6	± 9
	−45° 12460	11·8		−45° 31′·6	+ 19				± 8
1173	F.S. 18188	9·3	G5	18 24 33	− 125	− 137	±22	+ 12	± 6
	−46° 12449	9·8		−46° 22′·1	− 106				± 5
1174	F.S. 18158	...	Go	18 29 11	− 160	− 159	±30	+ 38	± 7
	−44° 12736	10·9		−44° 23′·1	− 158				± 6
1175	F.S. 18379	...	K5	18 50 32	− 54	− 247	±29	+ 21	± 8
	−47° 12632	11·9		−47° 34′·5	− 54				± 6
1176	Z.C. 18196	8·82	Ko	19 21 28	− 56	− 278	±31	+ 31	± 8
	−50° 12509	9·6		−50° 04′·3	− 51				± 6
1177	Z.C. 18306	9·3	G5	19 32 22	− 38	− 248	±23	+ 14	± 6
	−48° 13200	9·9		−48° 24′·8	− 38				± 5
1178	F.S. 18799	...	M1	19 35 44	− 47	− 242	±34	+ 34	± 8
	−45° 13383	11·4		−45° 18′·5	− 98				± 6
1179	F.S. 18800	...	Go	19 35 50	− 79	− 177	±23	+ 8	± 5
	−45° 13385	10·8		−45° 16′·7	− 106				± 4
1180	F.S. 18902	10·3	F8	19 48 02	− 2	− 433	±33	+ 21	± 8
	−42° 14547	10·4		−42° 53′·6	+ 27				± 6
1181	A.G. 7147	8·8	G5	20 11 27	− 160	− 304	±26	+ 10	± 7
	−11° 5285	9·6		−11° 16′·9	− 162				± 5
1182	α^1 Capricorni	4·55	Gop	20 12 06	+ 16	+ 4	±24	0	± 6
	P.G.C. 5197	5·11		−12° 49′·0	− 3				± 4
1183	α^2 Capricorni	3·77	G5	20 12 30	+ 60	+ 5	±34	+ 50	± 9
	P.G.C. 5202	4·55		−12° 51′·3	+ 52				± 5
1184	Z.C. 18819	8·9	F8	20 21 09	+ 86	− 128	±29	+ 11	± 7
	−43° 14001	9·4		−42° 56′·7	+ 95				± 6
1185	Z.C. 18820	8·1	F8	20 21 12	+ 89	− 129	±27	+ 6	± 7
	−43° 14003	8·7		−42° 56′·7	+ 86				± 5
1186	F.S. 19178	9·9	G5	20 26 59	+ 125	− 157	±26	+ 28	± 7
	−48° 13606	10·6		−48° 13′·5	+ 94				± 6
1187	F.S. 19181	...	Go	20 27 10	+ 74	− 200	±30	+ 3	± 9
	−48° 13610	11·8		−47° 59′·5	+ 70				± 8
1188	F.S. 19220	...	K5	20 31 53	+ 223	− 385	±23	+ 26	± 6
	−44° 14065	11·6		−44° 04′·2	+ 219				± 5
1189	Ci. 20, 1225	8·1	K5	20 38 57	+ 267	− 350	±30	+109	± 8
	−31° 17815	9·7		−31° 41′·6	+ 264				± 7
1190	Ci. 20, 1257	...	...	20 59 26	− 970	−2090	±35	+ 66	±10
	Ross 769	12·4		−17° 18′·1	− 929				±10

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				h m s					
1191	Z.C. 19431	9·2	G5	21 25 04	+ 338	+ 22	±25	+ 12	± 7
	−46° 13985	10·1		−46° 20′·4	+ 350				± 5
1192	Z.C. 19521	9·1	Ko	21 35 53	+ 193	− 283	±32	+ 48	± 8
	−41° 14616	9·4		−41° 34′·3	+ 181				± 6
1193	G.C. 30703	7·67	Go	21 50 37	+ 38	− 228	±28	+ 1	± 8
	−50° 13533	8·7		−50° 10′·0	+ 31				± 6
1194	F.S. 19869	...	K7	22 13 44	+ 256	− 178	±39	+ 29	±10
	−49° 13807	12·3		−49° 33′·5	+ 232				± 9
1195	F.S. 19932	...	Ko	22 22 34	+ 374	− 36	±24	+ 31	± 6
	−50° 13685	11·0		−50° 05′·7	+ 382				± 5
1196	U.O.C. 48	...	...	22 29 49	+ 280	+ 140	±39	+ 32	±11
	−52° 10217	10·5		−52° 09′·3	+ 279				± 6
1197	Z.C. 20128	10·1	F8	22 42 37	+ 35	− 310	±26	− 16	± 7
	−46° 14447	10·4		−46° 35′·0	+ 26				± 4
1198	Z.C. 20363	9·1	G5	23 09 04	+ 116	− 219	±31	+ 33	± 8
	−41° 15194	9·2		−40° 59′·1	+ 111				± 6
1199	F.S. 20439	...	...	23 36 34	− 213	− 320	±30	+ 25	± 7
	−43° 15465	13·3		−43° 17′·7	− 217				± 5
1200	F.S. 20454	...	Ko	23 39 52	+ 170	− 279	±37	+ 25	±10
	−48° 14598	12·4		−48° 49′·3	+ 183				± 7